Santa Clara Valley
Water District

FINAL
Indirect Potable Reuse Scenario Model Simulations

Indirect Potable Reuse Groundwater Studies

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List of Acronyms

AFY	acre-feet per year
cfs	cubic feet per second
DDW	Division of Drinking Water
District	Santa Clara Valley Water District
ft/d	feet per day
ft-NGVD29	feet National Geodetic Vertical Datum of 1929
HLA	Harding Lawson Associates
IPR	indirect potable reuse
Kh	horizontal hydraulic conductivity
SWRCB	California State Water Resources Control Board
Subbasin	Santa Clara Plain Groundwater Subbasin
Todd	Todd Groundwater
WEAP	District's regional water supply planning and operations model

Executive Summary

A numerical groundwater flow model of the Santa Clara Plain Groundwater Subbasin (less the Coyote Valley Region) and a portion of the San Mateo Plain Subbasin (referred to as Subbasin in this report) was used to simulate changes in groundwater levels and flow that would result from groundwater recharge by means of indirect potable reuse (IPR). Five scenarios representing various amounts, locations and methods of IPR recharge were simulated. Generally, these consisted of increased percolation at the existing Los Gatos recharge ponds (Los Gatos Ponds), injection directly into potable supply aquifers using new wells in an area north of the Los Gatos ponds, and percolation at the existing and a new off-channel pond along Coyote Creek near the Ford Pond site.

The numerical model was a version of IMOD, which is a recently-developed model that uses the U.S. Geological Survey's MODFLOW 2005 code (Todd, 2017). For the IPR simulations, model grid spacing was reduced to 250 x 250 feet near the recharge sites and the MODPATH post-processing program was applied to simulate subsurface travel time of recharged water. The simulations consisted of 360 monthly stress periods that used 1985-2014 hydrology for natural rainfall and stream flow recharge. Active recharge in ponds and creeks throughout the Subbasin and total groundwater pumping from the Subbasin were obtained from the output of a regional water supply planning and operations model (WEAP) that simulates all aspects of the Santa Clara Valley Water District's (District's) water supply system. The WEAP model treats the Subbasin as a simple "bucket" and cannot simulate local variations in aquifer characteristics, water levels, recharge and pumping within the Subbasin. The purpose of the simulations using the IMOD groundwater model was to add detail related to those processes. The groundwater model implemented the WEAP model output "as-is"; there was no iteration between the models and no adjustments to make the WEAP output more realistic with regard to groundwater processes.

Simulation results were evaluated in terms of depth to water, groundwater elevation, and travel time from points of recharge. IPR recharge raised simulated groundwater levels at Los Gatos Ponds by up to 80 feet in some months. Simulated water levels were occasionally within 10 feet of the ground surface at some of the ponds and also within a few feet of the bed elevation of Los Gatos Creek. Although the model did not indicate gains in creek flow or "flooded" cells near the ponds, the large thickness of model layer 1 precludes accurate simulation of water levels in the shallowest depth intervals. In the IPR injection well area, recharge raised simulated water levels by about 20 feet. There was no evidence of well interference, which is localized water-level buildup around individual wells that significantly reduces the capacity for water-level buildup at an adjacent well. Also, simulated groundwater levels in all model layers near the injection wells remained more than 20 feet below the ground surface. At the Ford Pond, water levels were as much as 15 feet higher with IPR recharge but remained more than 15 feet below ground surface at all times. At all three locations, IPR recharge had the greatest effect on water levels during droughts. Higher water levels and larger amounts of groundwater storage during extended droughts are a major objective of IPR recharge.

The horizontal travel times from IPR recharge locations to nearby potable supply wells was greater than 2 years for all of the Los Gatos Ponds and injection wells. After 10 years of travel time, recharged water reached several potable supply wells. Because of high permeability and groundwater flow velocities in the Santa Teresa region of the Subbasin, the simulated distances traveled by IPR water recharged at Ford Ponds area were relatively large. Simulated travel times to four wells were less than one year (ranging from 1-12 months). One additional simulation was completed to test the sensitivity of simulated travel times to several concurrent changes in model inputs expected to decrease travel times. Reasonable adjustments to layer thicknesses, vertical permeability and particle starting locations were implemented in the sensitivity simulation, and the effect was to shorten the simulated travel times to the four nearest wells: to 0.7-10 months.

Overall, simulation results confirmed that the aquifer system can accept the additional IPR recharge without causing problems with high groundwater levels or well interference, except at Ford Pond, where subsurface travel times to the nearest downgradient potable supply wells are shorter. At Ford Pond, four potable supply wells are located within one year travel time. Response retention time and pathogen reduction time (minimum travel time) per the State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW) Groundwater Replenishment with Recycled Water regulations have not yet been established for the IPR projects.

While the model travel times are deemed reasonable for planning purposes (with the DDW-required correction factor) for the Ford Ponds area, given the relatively short travel times and the proximity and number of nearby potable supply wells, the District should consider further field testing prior to implementing this Ford Ponds IPR project. Field testing could include local area pumping tests with observation wells and tracer testing prior to project startup.

1 Overview of Groundwater Model

The IMOD groundwater model simulates three-dimensional groundwater flow in the Santa Clara Plain Groundwater Subbasin (Santa Clara Subbasin less the Coyote Valley area). It was developed during 2015-2017 by combining and enhancing features of two prior Subbasin models (GMOD and XMOD) (Todd, 2017). IMOD retained the plan-view footprint of the prior models, as shown in **Figure 1**. The model has six layers. Layer 2 (second from top) represents a regional clay confining layer that extends inland from beneath San Francisco Bay. The other layers are defined partly by typical well screen depths, but not explicitly by geology. The Subbasin deposits consist of thin, laterally discontinuous clay, silt and sand layers. Around the perimeter of the Subbasin, the bottom of the groundwater model is the contact between unconsolidated alluvial deposits and bedrock. Where the Subbasin is thicker (near San Francisco Bay), the bottom of the simulated flow domain is set at 1,000 feet below sea level, which is deeper than almost all water supply wells.

A pre-processing program estimates dispersed recharge from rainfall, irrigation deep percolation and pipe leaks. Subsurface inflow from Coyote Valley and to a lesser degree from bedrock hills adjoining the Subbasin are simulated in the model as general-head boundaries, where the amount and direction of flow depends on concurrent simulated water levels. Subsurface flow to or from San Francisco Bay is simulated in the same manner. Flow between the groundwater system and overlying hydraulically coupled streams is dynamically simulated based on concurrent water levels. The model simulates stream flow as well as groundwater flow, with mass conserved in both domains. Stream flow included unregulated natural rainfall runoff, local reservoir releases, and releases of imported water into creek channels for supplemental percolation. Percolation of imported water at ponds was simulated as injection into model layer 1, with the amounts obtained from historical pond operation records. Pumping by water supply and remediation wells was obtained from detailed records maintained by the District.

The uniform coarse-grid version of the model (1,000 x 1,000-foot cells) was calibrated to match observed groundwater levels and stream flows during calendar years 1985-2014. Monthly simulated water levels were compared to measured water levels at 54 well locations, five of which were nested monitoring wells with 4-5 separate well screen depths. The primary variables adjusted during model calibration were the zonal patterns and values of horizontal and vertical hydraulic conductivity (permeability) and aquifer storativity. After calibration, simulated water levels matched measured water levels at most locations reasonably well and met industry-standard criteria for acceptable model calibration.

A fine-grid version of the model was prepared for the purpose of simulating IPR recharge. Selected model grid rows and cells were split in half to reduce the size of model cells to 250 x 250 feet near IPR recharge sites. The purpose of reducing cell size was to increase the accuracy of travel time estimates over periods of a few months and to better estimate the amount of water-level mounding around injection wells. The fine model grid and hydraulic conductivity zonation pattern for model layers 3-5 near the IPR sites are shown in **Figure 2**. The zones and parameter values are the same as in the coarse-grid model. Reducing the grid cell size had small effects on the calibration hydrographs. At some wells, simulated water levels differed from the coarse-grid simulated water levels by up to 3 feet, which is a small percentage of the overall range of water levels at most wells. The differences probably resulted from more concentrated stresses at pumping wells (the same volume of water extracted from a smaller cell area), resulting in greater localized drawdown. In a few cases, hydrograph wells and nearby pumping wells might have been in separate model cells, whereas they had shared a single cell in the coarse-grid model. There were no signs that converting to the fine grid significantly affected calibration results.

2 Assumptions and Input for IPR Simulations

- Simulations used the “fine grid” version of IMOD. Average model layer thickness and aquifer characteristics at the Los Gatos Ponds, injection well, and Ford Ponds areas are shown in **Table 1**. In the model, the boundary between the zone of relatively low hydraulic conductivity (15 feet per day (ft/d)) near Los Gatos Ponds and the zone of moderate hydraulic conductivity (90 ft/d) near the injection wells follows a line roughly perpendicular to Los Gatos Creek near McGlincy Pond (**Figure 2**).
- The simulation time step was monthly for the calendar year 1985-2014 period, which is the period used for model calibration. Rainfall recharge and natural stream flow were the historical values for that period, but the starting water levels for the IPR scenarios were the ending water levels from the historical calibration simulation.
- Five scenarios were simulated corresponding to five levels of IPR implementation, as characterized in **Table 2**.
- The locations of the IPR facilities are shown in **Figures 1** and **2**.

Table 1 Model Grid and Parameters near Proposed IPR Locations

Layer	Thickness (ft)	Horizontal Hydraulic Conductivity (ft/d)	Vertical Hydraulic Conductivity (ft/d)	Specific Storativity	Specific Yield
Los Gatos Ponds Area					
1	210	15	1	0.0001	0.12
2	20	15	1	0.0001	0.12
3	130	15	0.5	0.0001	0.12
4	180	15	0.1	0.0001	0.12
5	310	15	0.1	0.0001	0.12
6	Inactive	Inactive	Inactive	Inactive	Inactive
Injection Well Area					
1	210	90	1	0.00003	0.03
2	20	90	1	0.00003	0.03
3	130	90	1	0.00003	0.03
4	180	90	1	0.00003	0.03
5	310	90	1	0.00003	0.03
6	330	10	0.01	0.00003	0.03
Ford Pond Area					
1	140	300	1	0.00003	0.03
2	20	300	1	0.00003	0.03
3	20	300	1	0.00003	0.03
4	Inactive	Inactive	Inactive	Inactive	Inactive
5	Inactive	Inactive	Inactive	Inactive	Inactive
6	Inactive	Inactive	Inactive	Inactive	Inactive

specific storativity and specific yield are dimensionless

IPR - indirect potable reuse ft - feet

ft/d - feet per day

Table 2 Summary of WEAP Model Scenario Specifications and Results

Scenario	Metric of Implementation	IPR Recharge (AFY)				Basinwide Pumping (AFY)
		Los Gatos Ponds[a]	Injection Wells	Ford Ponds[a]	Total	
1	Capacity	0	0	0	0	NA
	1985-2014 average	0	0	0	0	101,400
2	Capacity	24,000	0	0	24,000	NA
	1985-2014 average	18,080	0	0	18,080	109,800
3	Capacity	24,000	6,000	0	30,000	NA
	1985-2014 average	18,143	4,442	0	22,585	110,700
4	Capacity	24,000	11,000	0	35,000	NA
	1985-2014 average	16,925	9,502	0	26,427	111,800
5	Capacity	24,000	11,000	4,200	39,200	NA
	1985-2014 average	15,663	9,861	2,098	27,622	112,434

a - Only IPR water percolation shown here. Imported water and creek diversions are also percolated at Los Gatos and Ford Ponds, but at lower priority than IPR water. Total Los Gatos Ponds percolation was 11,877 AFY, 19,788 AFY, 18412 AFY, 17,137 AFY, and 15,874 AFY for Scenarios 1-5, respectively. Total Ford Pond percolation in Scenario 5 was 4,015 AFY.

AFY - acre-feet per year NA - not applicable IPR - indirect potable reuse

- The District simulated each scenario with a regional water supply planning and operations model (WEAP) that selected monthly allocations during hydrologic years 1922-2015 for numerous imported and local water supply sources and storage facilities. WEAP results for the following four variables for calendar years 1985-2014 were used as input to the IMOD groundwater flow model:
  - Percolation of IPR water at Los Gatos Ponds and Ford Ponds
    - For the Los Gatos Ponds, WEAP-simulated percolation was allocated among all six pond groups based on their historical percolation rates.
    - For the Ford Ponds, percolation was allocated uniformly among the model cells covering the two pond parcels.

    - Net evaporation (evaporation minus rainfall) was subtracted from recharge at each pond every month. The subtracted volume equaled the one-dimensional net recharge rate multiplied by pond area.
    - Percolation ponds were represented in IMOD as layer 1 injection wells. Thus, all of the WEAP allocation entered the aquifer with no adjustments or limitations related to clogging or high water table conditions. The WEAP model capped the percolation allocations at the maximum capacities estimated by the District.
- Injection of IPR water at sixteen wells north of Los Gatos Ponds
    - Based on prior simulations, 16 well locations were selected from a candidate list of 27 locations. The “Group 3” set of locations was selected because of its central location and compact size. Prior simulations indicated no problems associated with well interference and excess head build-up.
    - The IPR wells were assumed to inject into model layer 5 (from approximately 540-850 feet below ground surface in the injection well area), which is the layer from which most nearby municipal pumping occurs.
    - The maximum monthly WEAP allocation for IPR injection in Scenario 3 was equivalent to 16 wells injecting continuously at 230 gpm throughout the month. For Scenarios 4 and 5, the rate was 430 gpm.
- Total Subbasin-wide groundwater pumping
    - To be consistent with WEAP, total annual pumping in the IMOD model was adjusted to equal total annual pumping in the WEAP model.
    - Because retail purveyors would be the only pumpers likely to be affected by conjunctive use, only retail pumping was adjusted each year. However, the amount of adjustment was such that total Subbasin-wide pumping (including agricultural, domestic and other pumpers) matched the WEAP output.
    - The monthly variations in IMOD pumping (as a proportion of annual pumping) equaled the historical monthly proportions during 1985-2014.
- Releases of managed water to local creeks for percolation
    - Stream flows provided as input to the IMOD stream package consist of a combination of natural runoff and managed releases. WEAP simulates only the managed releases. That component of stream flow used the WEAP allocations, whereas the natural component consisted of historical amounts during 1985-2014.
    - A comparison among WEAP results for all streams with managed flow revealed that five streams accounted for 83 percent of the variation among scenarios: Calabazas, Los Gatos, Penitencia, Ross/Lone Hill and Saratoga. For efficiency, only those creeks were updated for each scenario in the IMOD model.

3 Modeling Results

3.1 WEAP Output

Several aspects of the WEAP model output must be understood in order to make sense of the IMOD model output, because IMOD implemented the WEAP output without modification.

- Actual amounts of allocation by WEAP are much smaller on average than the nominal capacity.
  - When WEAP calculates the Subbasin as full, it discontinues IPR recharge. Consequently, average annual IPR recharge during 1985-2014 was 76-82 percent of IPR capacity for all of the scenarios. Capacity is a constraint only during droughts. In other words, full IPR capacity was only used during droughts.
  - When the combined capacities of the ponds and injections wells are greater than the total IPR allocation in a given month, WEAP divides it among the facilities. Thus, although total IPR recharge during 1985-2014 increased from Scenario 1 to Scenario 5, the amount of recharge at the Los Gatos Ponds was greatest in Scenario 2, when no other IPR facilities were assumed to operate. The Los Gatos Pond IPR percolation decreased from Scenario 2 through 5 because of increasing capacity available at other IPR facilities.
- WEAP often allocates on an on/off basis for each facility in a given month, rather than apply fractional allocations among multiple facilities. Sometimes a single “on” month will occur in the middle of a sequence of “off” months. This is illustrated in **Figure 3**, which shows monthly IPR allocations for Los Gatos Ponds percolation for Scenarios 2 and 5. This results in large fluctuations in water levels near IPR facilities during certain segments of the simulation period, which can complicate interpretation of hydrographs and water-level contour maps, and which is unlikely to reflect actual operations.

3.2 IMOD Simulation Results

3.2.1 Water-Level Hydrographs

Groundwater levels in all scenarios are generally higher than historical water levels. This is illustrated by water-level hydrographs at twelve locations near the IPR sites. The locations are shown in **Figure 2**, and simulated water levels under Scenario 1 are shown in **Figure 4**. Even in the absence of IPR recharge, water levels are higher than they historically were, particularly during the first half of the simulation. Those years corresponded to 1985-1999, which historically was a period of rapid Subbasin recovery due to new sources of imported water. Those sources were assumed to continue in the future, so the scenarios do not include a large initial recovery similar to the historical one.

In wet conditions such as March 1994, simulated water levels near some of the Los Gatos Ponds were within 10-15 feet of the ground surface. Simulated water levels in the Budd and McGlincy Ponds were higher than the creekbed elevation of Los Gatos Creek (150 ft-NGVD29) immediately below a dam located near Camden Avenue, 0.2 mile upstream of the McGlincy Ponds. The model did not indicate groundwater seepage into the creek in that area. However, the large thickness of the top model layer (about 210 feet in that area), precludes accurate simulation of head and flow within the uppermost 20 feet of the groundwater system. Installation of shallow piezometers between the ponds and the creek would provide a more reliable means of detecting possible seepage from the ponds into the creek.

At a regional scale, increased pond percolation was associated with decreased net recharge from streams because higher water levels in model layer 1 tended to decrease head-dependent percolation from streams and increase head-dependent seepage into streams at various times and locations. The amount of IPR pond percolation ranged from 17,137 acre-feet per year (AFY) in Scenario 4 to 19,889 AFY in Scenario 5 (**Table 1**). Net recharge from streams averaged 1,390 AFY less than baseline (Scenario 1) in Scenario 4 and 2,160 AFY less in Scenario 5. The decrease in net stream recharge under IPR Scenarios 2 through 5 ranged from 4.3-6.7 percent of baseline net stream recharge and ranged from 8.1-10.9 percent of the amount of IPR pond percolation.

Recharge and pumping create substantial vertical head gradients at some locations and smaller ones at others. For example, percolation at the Los Gatos Ponds creates 10-80 feet of simulated water-level (head) difference between model layers 1 and 5 at Page, Sunnyoaks and Budd Ponds. Two municipal production wells (07S01W22E002 and 07S01W15E001) pumping in deeper layers also create a vertical gradient (0-30 feet of difference between layers 1 and 5). Scenario 1 includes no percolation at Ford Ponds, and there was essentially no difference in water levels among the three active model layers at that location, partly because about 75 percent of the basin thickness is in model layer 1.

Figure 5 compares simulated groundwater levels among all the scenarios at each of the twelve locations. In each graph, the model layer most relevant to recharge was selected for display (layer 1 for pond percolation sites and layer 5 for injection well sites). At the four Los Gatos Ponds sites for which hydrographs are shown, there was a large increase in water level from Scenario 1 (0 AFY IPR recharge) to Scenario 2 (19,788 AFY IPR recharge) during the 1987-1992, 2007-2009 and 2013-2014 drought periods. For example, at the end of 2014, water levels under Scenario 2 were 80 feet higher than under Scenario 1. Water levels were roughly similar among Scenarios 2 through 5. Simulated water levels were within 10 feet of the ground surface elevation at Page, Budd and Sunnyoaks Ponds in wet years. Results for Camden and Oka Ponds were similar, with water levels almost reaching the ground surface elevation. The WEAP model does not account for groundwater flow hydraulics and estimates a "full" Subbasin condition based on storage across the entire Subbasin. In practice, percolation at each of the Los Gatos Ponds could be managed on the basis of water levels in nearby shallow monitoring wells to avoid any problems associated with high water table conditions.

The hydrographs for the 16 IPR injection wells show that the simulated potentiometric surface for model layer 5 was always at least 30 feet below ground surface for all scenarios. This means that the proposed rates and distribution of injection would not result in flowing wells or high water table conditions due to excessive localized head buildup.[1] Simulated water levels were progressively higher for scenarios with increasing amounts of injection, but water-level differences were only about 5-20 feet. This indicates that average aquifer transmissivity in the IPR injection area is sufficiently high to convey the injected water away from the wells without a large gradient. Results for two downgradient water supply wells were similar to those for the IPR wells (see hydrographs 22E2 and 15E1 in **Figure 5c**).

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[1] Simulation results show average water levels across the area of a model cell. Head at the well itself would be higher than this average.

The modeling results are based on calibrated average aquifer hydraulic characteristics over broad regions. Although simulation results do not show problems with excessive head buildup at injection wells, local heterogeneities in alluvial deposits or nearby wells acting as conduits for vertical flow might cause heads in shallow aquifer zones to rise more than the amounts simulated by the model at some IPR injection well locations.

At the Ford Ponds, Scenario 5 is the only scenario with IPR percolation. The WEAP model allocated the full amount of percolation in almost every month during 1985-2014, and consequently simulated water levels at the ponds were 10-15 feet higher than historical measured and simulated baseline (Scenario 1) water levels most of the time. Simulated water levels were 20 feet or more below the ground surface elevation at the Ford Ponds site. Percolation at Ford Ponds in Scenario 5 raised simulated water levels at a nearby downgradient well (6R8) by almost as much as at the ponds. Simulated groundwater levels at Ford Ponds reached the bed elevation of Coyote Creek (approximately 189-193 feet along the reach adjacent to the pond) in 10 years of the simulation; although, the model did not simulate a gain in stream flow. However, the rate of percolation from the creek decreased from 1.5 cubic feet per second (cfs) per mile upstream of the ponds to 0.8 cfs per mile next to the ponds. Creek-pond interaction is controlled by hydrogeologic conditions within the uppermost 20 feet of the groundwater system and over horizontal distances smaller than one model cell. Consequently, actual conditions could differ from simulation results and should be verified through field observations of shallow groundwater levels and signs of seepage along the creek channel.

3.2.2 Depth to Water in the Los Gatos Ponds and Injection Well Areas

If simulated water levels in model layer 1 approach the ground surface elevation, there is a possibility that IPR recharge could create high water table conditions at those times. A high water table can cause problems such as flooded basements, waterlogged soils, poor tree health, soil liquefaction during earthquakes and rejected recharge. It must be noted, however, that even under existing conditions simulated water levels for model layer 1 are above the ground surface over a broad region extending from downtown San Jose to San Francisco Bay. These elevated water levels are produced in part by upward leakage from aquifers below the regional confining layer, where water levels (head) are even farther above the ground surface. In reality, streets, basements and soils are not flooded. Presumably, shallow groundwater flows into creeks, storm drains and sanitary sewers by gravity or by sump pumps, thereby preventing the water table from actually reaching the land surface. The model does not simulate many of these shallow and/or artificial flow paths. Thus, simulated layer 1 water levels at or above the land surface suggests that a problem could occur but might not occur in practice.

Figure 6 shows contours of the simulated depth to water in model layer 1 in December 1993 for Scenarios 1 and 5 in the vicinity of the Los Gatos Ponds and injection well areas (southwest Subbasin area). In the Los Gatos Ponds area, December 1993 was the month with the highest simulated water levels for Scenario 1, and water levels were almost as high at the March 1994 maximum in the other scenarios. In Scenario 1, the depth to groundwater was 40-60 feet in the injection well area and as little as 10 feet in the Los Gatos Ponds area. However, depths to water less than 50 feet occurred only in the immediate vicinity of Page, Sunnyoaks and Budd Ponds. Scenario 5 raised the water table approximately 5 feet near those ponds, and the mounding is also fairly localized. Simulated depth to water increased to 40 feet within 0.5 mile of the ponds. These results further indicate the need to install or acquire nearby shallow monitoring wells to support real-time management of percolation based on current water levels.

Near the IPR injection wells, depth to water is a potential issue if injection raises the potentiometric head to near or above the ground surface. This could cause flowing wells or eventually shallow water table conditions in surficial aquifers. Vertical conduits such as abandoned wells, seasonal use wells, and cathodic production wells could facilitate surface discharges or movement of water from the zone of injection to shallower aquifers. **Figure 7** shows contours of depth to groundwater in model layer 5 in December 1993, which had some of the highest water levels of the 30-year simulation period. Under Scenario 1 (no injection), depth to water near the IPR wells was 30-60 feet. Under Scenario 5 (maximum injection) depth to water was 35-55 feet, with negligible localized mounding. The WEAP model was allocating water for injection in that month and for over a year prior. The small difference in water level is consistent with the hydrographs. IPR injection raised water levels during droughts—by up to 20 feet for Scenario 5. In all cases, however, heads remained well below the ground surface.

Injection could potentially raise water levels at nearby injection wells (well interference). The groundwater model is reasonably capable of simulating well interference, because model grid cell spacing (250 x 250 feet) is smaller than the minimum distance between the IPR injection wells (750 feet). The simulation results did not show substantial water-level build-up at cells with injection wells. When contoured at an interval of 2 feet, the simulated water level surface did not exhibit closed contours around injection well cells. Aquifer transmissivity in the injection well area was sufficiently high that the injection wells collectively raised water levels over the entire area but without distinct cones of water-level mounding around individual wells.

3.2.3 Groundwater Elevations in the Los Gatos Ponds and Injection Well Areas

Groundwater elevation contours provide an indication of groundwater flow directions and gradients near the IPR sites. They are not the basis for design or regulatory constraints, but they provide a general picture of how groundwater flow changes as a result of additional recharge. **Figure 8** shows contours of simulated groundwater elevations in model layer 1 in December 1993 for Scenario 1 **(Figure 8A** - no pond recharge) and Scenario 5 **(Figure 8B** - 15,874 AFY average annual percolation). In both maps, the regional gradient is northward, and there is localized radial flow outward from the Los Gatos Ponds. With additional recharge, the pattern is the same but the gradient is steeper. Water table mounding beneath the ponds influences contours up to about 1 mile from the ponds.

Figure 9 shows elevation contours for model layer 1 in November 2014. This month was selected for illustration because there was a particularly large difference in water levels between Scenario 1 (**Figure 9A**) and Scenario 5 (**Figure 9B**). With no IPR percolation at the ponds, the regional gradient was uniform but relatively steep in the pond area (coinciding with a zone of lower horizontal hydraulic conductivity), and flattened out to the north (in a zone of higher hydraulic conductivity). With increased pond percolation, mounding beneath the ponds was evident, with locally radial flow and steeper gradients, similar to the December 1993 results.

Injection at IPR wells raised layer 5 water levels, but with less localized mounding. Results for December 1993 (a time of high water levels) are shown in **Figure 10**. Contours had similar shapes under Scenario 1 (**Figure 10A**) and Scenario 5 (**Figure 10B**), but were shifted north to reflect the higher water levels under Scenario 5. Localized mounding was more evident but still modest in November 2014 (a time of low water levels), as shown in **Figure 11**. Water levels were about 20 feet higher under Scenario 5, and contour curvature indicating slight mounding is noticeable up to about 1 mile from the IPR well cluster. Although the contours appear similar at first glance, IPR recharge raises layer 5 water levels over a large part of the Subbasin during droughts. **Figure 12** shows the difference in water levels between Scenario 1 (no IPR recharge) and Scenario 5 (maximum IPR recharge) in November 2014. The maximum increase in water level was about 30 feet near Los Gatos Ponds. Increases of 10 or more feet extended several miles to the east and west, and increases greater than 0 feet occurred throughout the eastern part of the Subbasin and along the southwest Subbasin margin.

3.2.4 Depth to Water and Groundwater Elevations in Ford Pond Area

IPR percolation at Ford Pond was included only in Scenario 5. Under wet conditions such as in December 1993, depth to water was about 20 feet with percolation (Scenario 5) compared with 30 feet without percolation (Scenario 1), as shown in **Figure 13**. The effect of IPR recharge was more pronounced during droughts, as illustrated in **Figure 14** for November 2014. Pond recharge only slightly deflected the groundwater elevation contours as shown in **Figure 14A**. The effect of percolation can be seen more clearly in **Figure 14B**, which shows the difference in simulated groundwater elevation between Scenarios 1 and 5. Pond percolation raised water levels by over 15 feet at the ponds and by more than 10 feet out to distances of 1-2 miles from the ponds.

3.3 Subsurface Travel Times of Recharged Water

The direction and rate of movement of percolated and injected recycled water in the groundwater system was simulated using the MODPATH add-on to the MODFLOW2005 simulation that is the basic component of IMOD. MODPATH uses a particle-tracking approach, calculating the movement of hypothetical particles of water based on the flow vector at the particle location at each time step of the flow simulation. It converts the Darcy velocity (flow over the full aquifer cross-sectional area) to pore velocity by dividing by effective porosity, which was 0.2 (dimensionless) in these simulations. For the MODPATH simulations, lines of particles were specified along the edges of IPR ponds and tight circles of particles were specified around the injection wells. For ponds, particles were assumed to start at the vertical midpoint of layer 1 to provide a conservative estimate of the downward component of particle movement. For injection wells the particles started at the midpoint elevation of layer 5. Particle movement was tracked for a period of 10 years starting in year 4 of the 30-year simulation period (that is, corresponding to 1989-1998 hydrologic conditions). The results did not exhibit noticeable variations in particle movement from year to year, so results were not greatly affected by selection of the tracking period. However, a period with active IPR recharge was selected to ensure that localized movement near the IPR facilities was correctly represented, particularly for the first 2 years of particle movement.

Figure 15 shows a map of horizontal particle movement in the southwest Subbasin area under Scenario 5. The dots along each particle trace represent elapsed times of 0, 1, 2, 6 and 12 months plus 2 through 10 years. To simplify reading the map, particle locations after 1 year of travel are highlighted in green. DDW regulations for groundwater replenishment with recycled water require that recycled water be retained underground prior to extraction at a potable water supply wells for a sufficient time to meet the project-specific response retention time and pathogen reduction time. The response retention time is the amount of time needed to respond to the recharge of recycled water that does not meet regulatory requirements and potential impacts nearby potable water supply wells. While these times have not yet been established for the District's IPR projects, retention times for other established IPR projects typically range from 3 to 7 months. Two months is the minimum response retention time established in the regulations. To account for inaccuracies inherent in any modeling analysis, the simulated travel time is multiplied by 2, per the regulations. Accordingly, the 1 year simulated travel time would represent a retention time of 6 months for regulatory permitting purposes.

Potable supply wells are shown in red on the map. Particles reached several of the wells (map labels 27P10, 22E13, 15R1, 23A2, 23E2 and 23R7), but not within 1 year. In addition to horizontal movement, MODPATH simulates the vertical movement of particles. After 10 years of travel time, some particles originating from Los Gatos Ponds had migrated downward as far as model layer 4. Most remained in higher layers, however. Particles originating from IPR injection wells remained in layer 5 throughout the simulation because it is a thick layer with large amounts of municipal pumping, so flow is predominantly horizontal. Thus, in the southwest Subbasin area, subsurface travel times from all of the IPR recharge facilities to downgradient potable supply wells are greater than 1 year.

Particle movement in the Ford Ponds area is much greater because of exceptionally high hydraulic conductivity in that part of the Subbasin. **Figure 16** shows particle-tracking results for Scenario 5. Over 10 years, particles moved as much as 2.6 miles downgradient. Particles reached four existing potable supply wells within 1 year (map labels 7H4, 8G2, 8M7 and 8Q2). Particles gradually moved downward, with some reaching layer 3 (the lowest active layer in this area) after 10 years. Most particles remained in layer 1, which comprises most of the Subbasin thickness at that location.

Figure 17 shows simulated particle locations for each month during the first year of travel. Nearby potable supply wells are labeled by the last three or four characters of the well number. Simulated travel times for the nearest potable supply wells are as follows:

Well 8Q2	1 month
Well 8M7	10 months

Well 7H4	12 months
Well 8G2	12 months (approx.)

3.4 Sensitivity Test of Ford Pond Area Model Parameters

Some of the model parameters that affect subsurface travel time are estimated. In particular, the amount of vertical particle movement relative to horizontal movement is uncertain. The sensitivity of simulated particle travel to alternative estimates for several parameters was investigated by repeating the simulation with values that tended to decrease the simulated rate of downward movement of particles. Given that well screens are typically tens of feet below the water table, downward travel time could be greater than horizontal travel time for wells close to the ponds. Several changes were implemented concurrently in the sensitivity test. First, the bottom elevations of model layers 1 and 2 were raised throughout the Santa Teresa area where Ford Pond are located. By so doing, the thicknesses of layers 1, 2 and 3 at the proposed ponds were changed from 116 feet, 20 feet and 20 feet to 49 feet, 50 feet and 57 feet, respectively. The revised bottom elevation of layer 1 is at an elevation of about 140 ft-NGVD29, corresponding to the approximate bottom elevation of a surficial zone of predominantly fine-grained materials evident in a number of wells in the area (but notably, not all wells). The starting point of the particles in the vertical dimension was changed from a depth equal to 40 percent of the thickness of layer 1 to 10 percent. In conjunction with the decreased thickness of layer 1, particle starting depths decreased from 46 feet to 5 feet below the water table. Finally, the vertical hydraulic conductivity throughout the Santa Teresa area was decreased from 10 ft/d to 2 ft/d. All three of these changes were expected to increase the vertical travel time of particles from the ponds down to the depths of the potable supply well screens but potentially decrease the rate of horizontal particle movement.

Alternative estimates of horizontal hydraulic conductivity (Kh) were not tested in the sensitivity simulation. The model has a value of 300 ft/d in all three model layers at the Ford Pond site and throughout most of the Santa Teresa area. This estimate was based on several lines of evidence. Mulitple “good quality” aquifer tests of wells in the “B aquifer” were conducted at the IBM site near the middle of the Santa Teresa area and produced Kh estimates ranging from 201 to 3,888 ft/d (HLA, 1999). The average thickness of the B aquifer was reported to be 30 feet. The model layers span the entire thickness of the Santa Teresa area, including fine-grained layers in addition to aquifers. Thus, the average Kh for a model layer would be smaller than the Kh for individual aquifer layers. A value of 300 ft/d produced a good match between measured and simulated hydrographs in the central part of the Santa Teresa area during model calibration. Average alluvial permeability could be smaller toward the edges of the Subbasin, assuming that over geologic time the alignment of the Coyote Creek channel—and associated coarse channel deposits—was more commonly near the center of the valley. However, the creek channel is presently close to the northern edge of the Subbasin (next to the Ford Pond site) and recent percolation tests at the Ford Ponds sites showed very high rates of percolation accompanied by negligible rises in water table elevation. Those results are consistent with a high value of Kh. For that reason, the 300 ft/d value near the center of the valley is also used at the Ford Pond site. Kh varies widely in nature, and the true average value of Kh at the site could plausibly be a factor of ten larger or smaller than the estimated value. The value of 300 ft/d is considered a reasonable average for simulating groundwater travel times. While there is always uncertainty in modeling parameters and assumptions, the model calibration based on the assumed Kh is deemed good. In addition, the DDW-required adjustment to travel times recognizes the modeling uncertainty and introduces a conservative correction factor. Finally, the DDW regulations require that a tracer test be conducted under operational conditions to more accurately measure travel times. Accordingly, the corrected model travel times are deemed reasonable for planning purposes. However, given the relatively short travel times in the Ford Ponds area and the proximity and number of nearby potable supply wells, the District should consider further field testing prior to implementing this IPR option. Field testing could include local area pumping tests with observation wells and tracer testing prior to project startup.

The results of the sensitivity simulation showed slower vertical travel but faster horizontal travel. **Figure 18** is a map similar to **Figure 17** showing horizontal particle travel by month from 0 to 12 months. Simulated particle travel times to the four nearest potable supply wells are:

Well 8Q2	0.7 month
Well 8M7	6 months
Well 7H4	10 months
Well 8G2	2 months (approx.)

The effect on vertical particle movement can be seen in **Figure 19**, which shows cross sections of particle traces near Ford Pond for the original simulation and the sensitivity test. In the original simulation (**Figure 19A**) almost all particles remained in model layer 1, which comprised 74 percent of the total aquifer thickness. In the sensitivity test **(Figure 19B**), most particles also remained in layer 1, even though its thickness was reduced to 31 percent of the total aquifer thickness. However, a subset of the particles initially moved eastward from the ponds—which is “up” the regional gradient but “down” the side of the localized recharge mound beneath the ponds—subsequently were pulled directly down to layer 3. This demonstrates that parameter values that generally retard downward particle movement do not prevent it.

The original simulation and the sensitivity test simulation are both considered reasonable representations of the groundwater flow system, given inherent uncertainties related to spatial variability of aquifer characteristics, limitations of available data and the effects of model discretization.

3.5 Percent Dilution Water in Ford and Los Gatos Ponds

The WEAP model allocates surface water, imported water purified water to the Ford and Los Gatos Ponds. While, per the DDW regulations, a purified (advanced-treated) recycled water IPR project can be implemented with 100 percent recycled water contribution (RWC), some surface water and imported water (dilution water) are delivered to the Ford and Los Gatos Ponds in the current version of the WEAP model. It is noted that current WEAP model allocation of purified and dilution water represents one set of demands, priorities and supply sources. The demand, priorities, supply sources and other model assumptions could be modified to result in different RWCs.

Based on the current WEAP model, for the projected model period representing 1985 to 2014 hydrologic conditions, the average RWC is 99 percent in the Los Gatos Ponds and 52 percent in the Ford Ponds.

3.6 Percent of Well Water Derived from Purified Water Recharge in Nearby Potable Supply Wells

Potable supply wells downgradient of IPR recharge areas draw water into the well radially from all directions. Consequently, some of the water entering the well will not derive from IPR recharge. The percentage of purified water entering the well depends on the strength of the regional gradient, the rate of purified water recharge and local variations in hydrogeology. Reverse particle tracking is one method for estimating the percentage of well water derived from purified water. This method uses the USGS MODPATH program, which post-processes the flow vectors produced by a MODFLOW simulation. In reverse tracking mode, it traces a hypothetical particle of water from a production well upgradient along the flow path that the particle followed to arrive at the well. By placing a circle of particles tightly around a pumping well location and counting the number of those particles that trace back to the IPR recharge area, the percentage of purified water in the well can be estimated.

The particle trace results need to be adjusted to account for mixing with ambient groundwater en route from the IPR recharge areas to the pumping wells. This was accomplished using the ZoneBudget post-processor. That program tabulates all inflows and outflows to and from a user-delineated group of model cells. ZoneBudget model cell groups were delineated encompassing the particle traces, including the production wells and the upgradient IPR recharge area. This was done for Well Field 1 located near and downgradient from the IPR Injection Wells, Well Field 2 located just east of the Injection Wells and Well Field 3 located northwest of the Los Gatos Ponds (**Figure 20**). Similarly, **Figure 21** shows particle traces for water supply wells near the Ford Ponds site. Half of the particles surrounding Well Field 1 traced upgradient to IPR injection wells in layer 5. Extrapolating the particle trajectories farther upgradient, some of them would also reach some of the Los Gatos Ponds (Budd, Sunnyoaks and Page). The ZoneBudget model cell group for this well field was drawn to include both the injection wells contributing flow to the production wells, Los Gatos Ponds IPR facilities and the region from which ambient groundwater would blend with IPR water. The ponds initially recharge layer 1, whereas the injection wells and production wells are screened mainly in layer 5. The pond percolation experiences additional dilution as it moves vertically downward through layers 2 through 4. To account for this dilution, a separate ZoneBudget model cell group was defined for each layer. By the time pond percolation reached layer 5, it comprised 11 percent of the water moving from the layer 4 ZoneBudget model cell group to the layer 5 group. As discussed in the previous section, under the current WEAP model projections, the water recharged at the ponds is expected to be 99 percent purified water and one percent storm water and/or imported water. Within the layer 5 Zone Budget model cell group, the IPR injection wells contributed an additional 15 percent of the water reaching Well Field 1. Thus, purified water comprises a total of approximately 26 percent of the water pumped by Well Field 1 under current WEAP model assumptions.

Similar calculations were done for the ZoneBudget model cell group surrounding Well Field 2, well 07S01W23A002 and upgradient IPR injection wells and percolation ponds. In that ZoneBudget model cell group, pond percolation comprised 4 percent of the water reaching Well Field 2, and purified water comprised 36 percent, resulting in a total of 40 percent purified water pumped by the wells.

Figure 20 also shows the ZoneBudget model cell group encompassing the Los Gatos Ponds and downgradient Well Field 3. That well field consists of three potable supply wells that were inactive during the model simulation period but could be used at some future date. The particle tracks and mixing calculations reflect the current passive flow of groundwater past the well screens. The model cell group for Well Field 3 is a subset of the cell group for Well Field 1. It receives IPR recharge only from upgradient ponds, not from injection wells. At least one well in Well Field 3 is screened primarily in model layer 4. ZoneBudget was used to route the pond percolation downward from layer 1 to layer 4, accounting for dilution by mixing with ambient groundwater flow within the model cell group in each layer. This resulted in an estimate that 38 percent of the water at the potable supply well screens would be purified water.

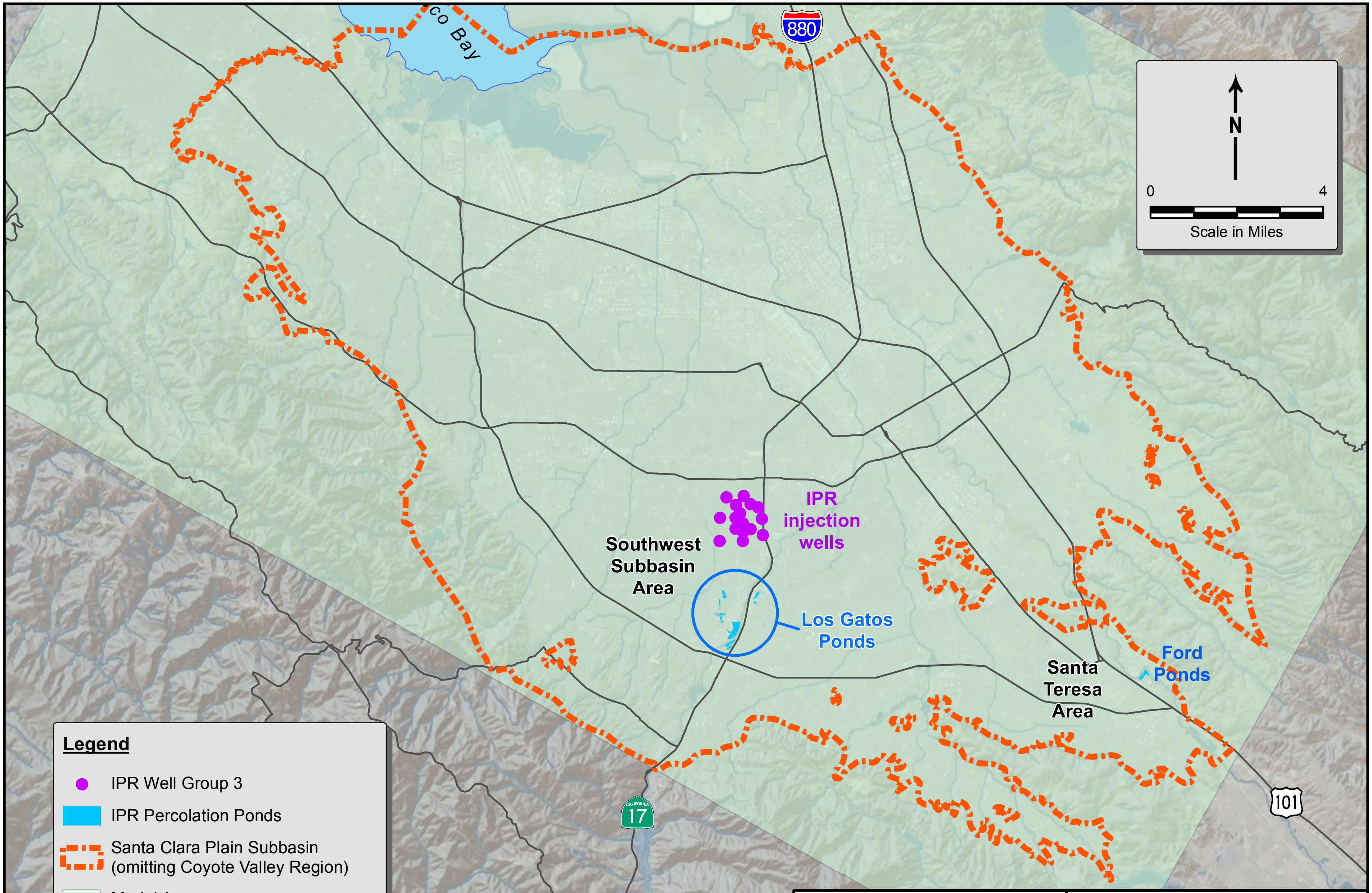
In the Ford Ponds area, total aquifer thickness is smaller and well depths are more variable. The ZoneBudget model cell group for that region included all three active model layers. All of the particle traces from downgradient potable supply wells traced back to the percolation ponds. However, there is a large regional groundwater flux in that area. The ZoneBudget analysis indicated that on average, pond water comprised 63 percent of the water pumped by the supply wells. However, based on the current WEAP projections, the ponds will percolate an average of 52 percent purified water 48 percent surface water and imported water. Thus, on average, water pumped by the downgradient wells would be 33 percent purified water.

4 References

Harding Lawson Associates (HLA), 1999, Appendix A: MODFLOW and RT3D Modeling Evaluation of Offsite B-Aquifer Pumping Reductions, IBM Facility, San Jose, CA, August 30.

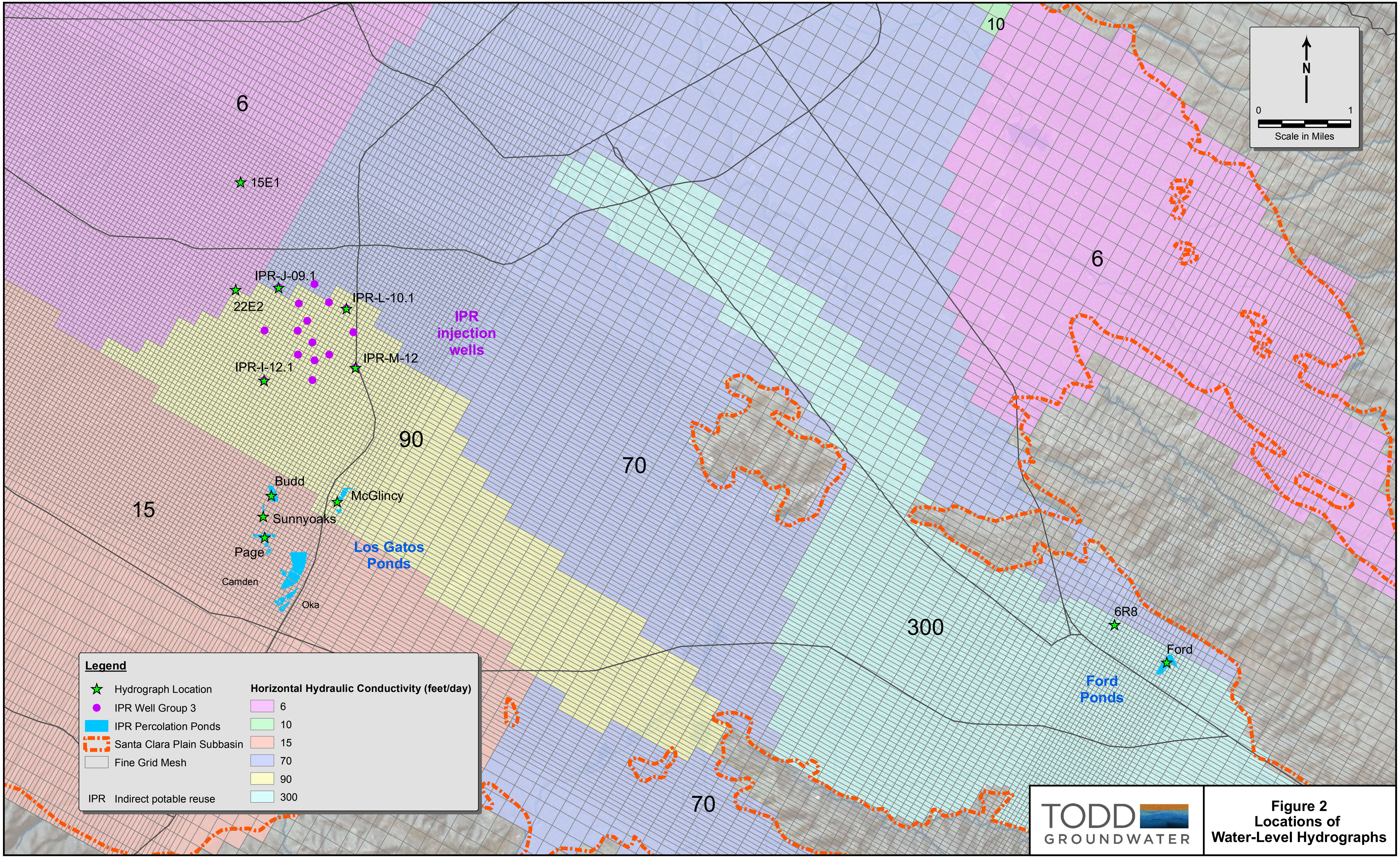
Todd Groundwater (Todd), 2017, Santa Clara Plain Groundwater Flow Model Development and Calibration, Indirect Potable Reuse Groundwater Studies, September.

Figures



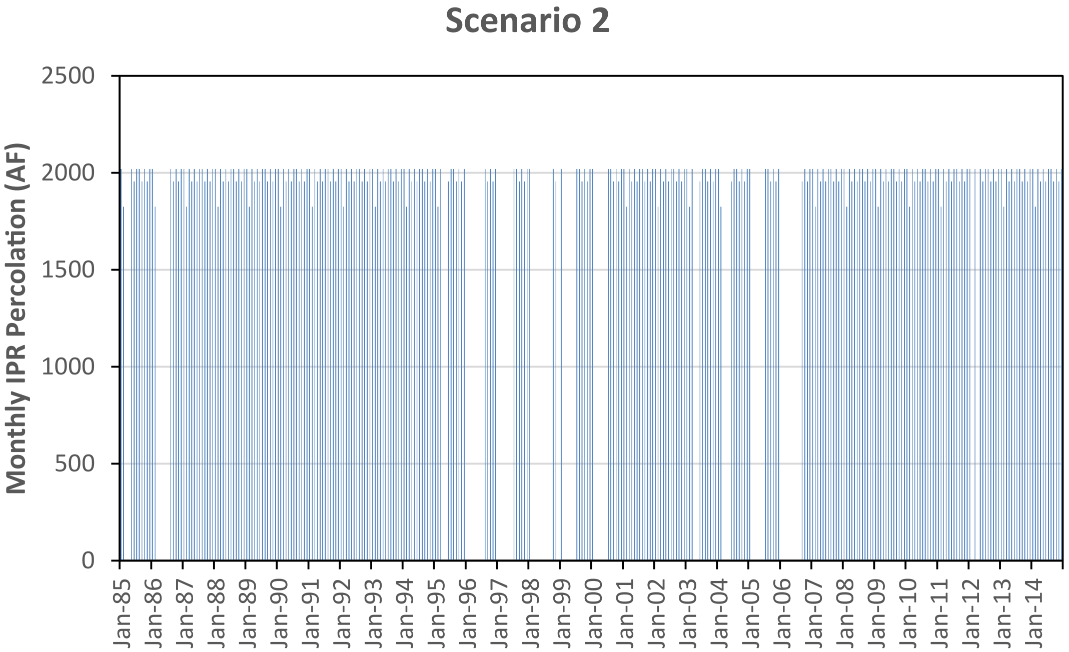
TODD GROUNDWATER

Figure 1
Locations of IPR Facilities

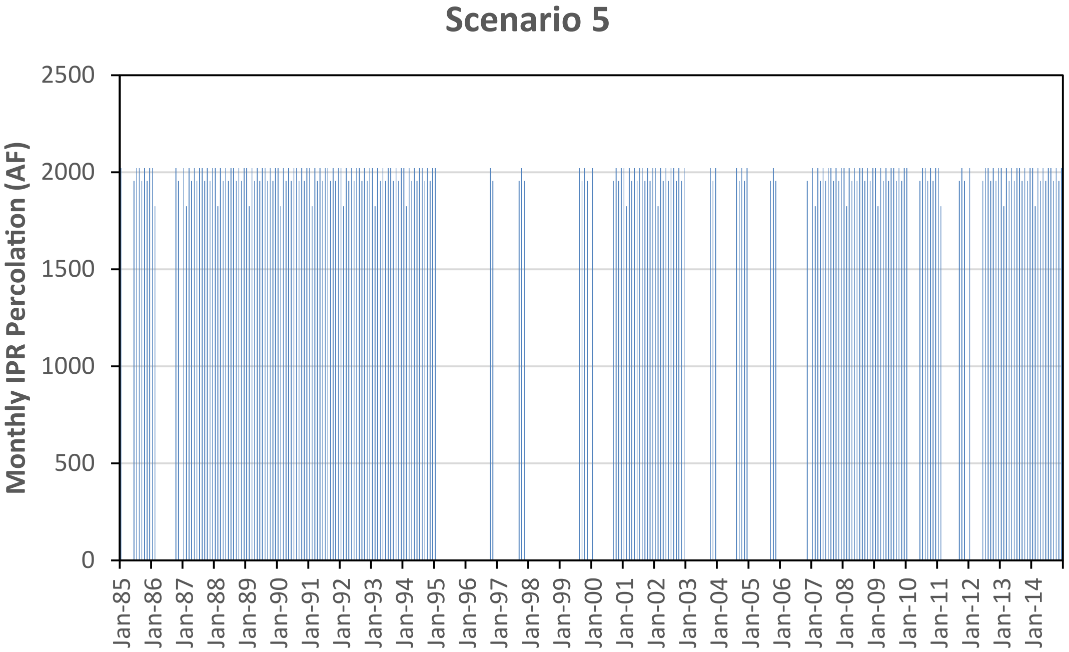


TODD GROUNDWATER

Figure 2
Locations of
Water-Level Hydrographs



Scenario 2

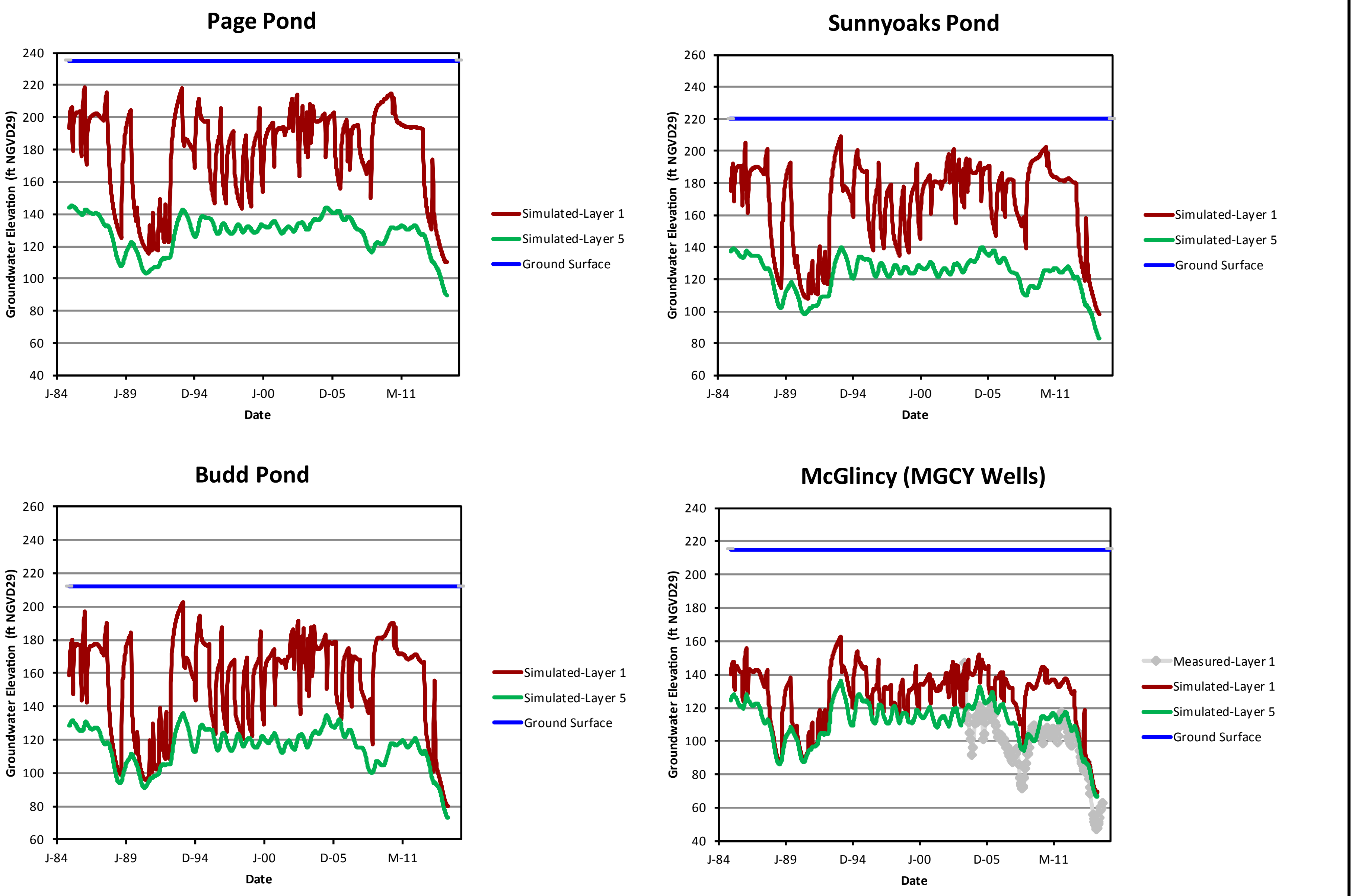


Scenario 5

AF - acre-feet

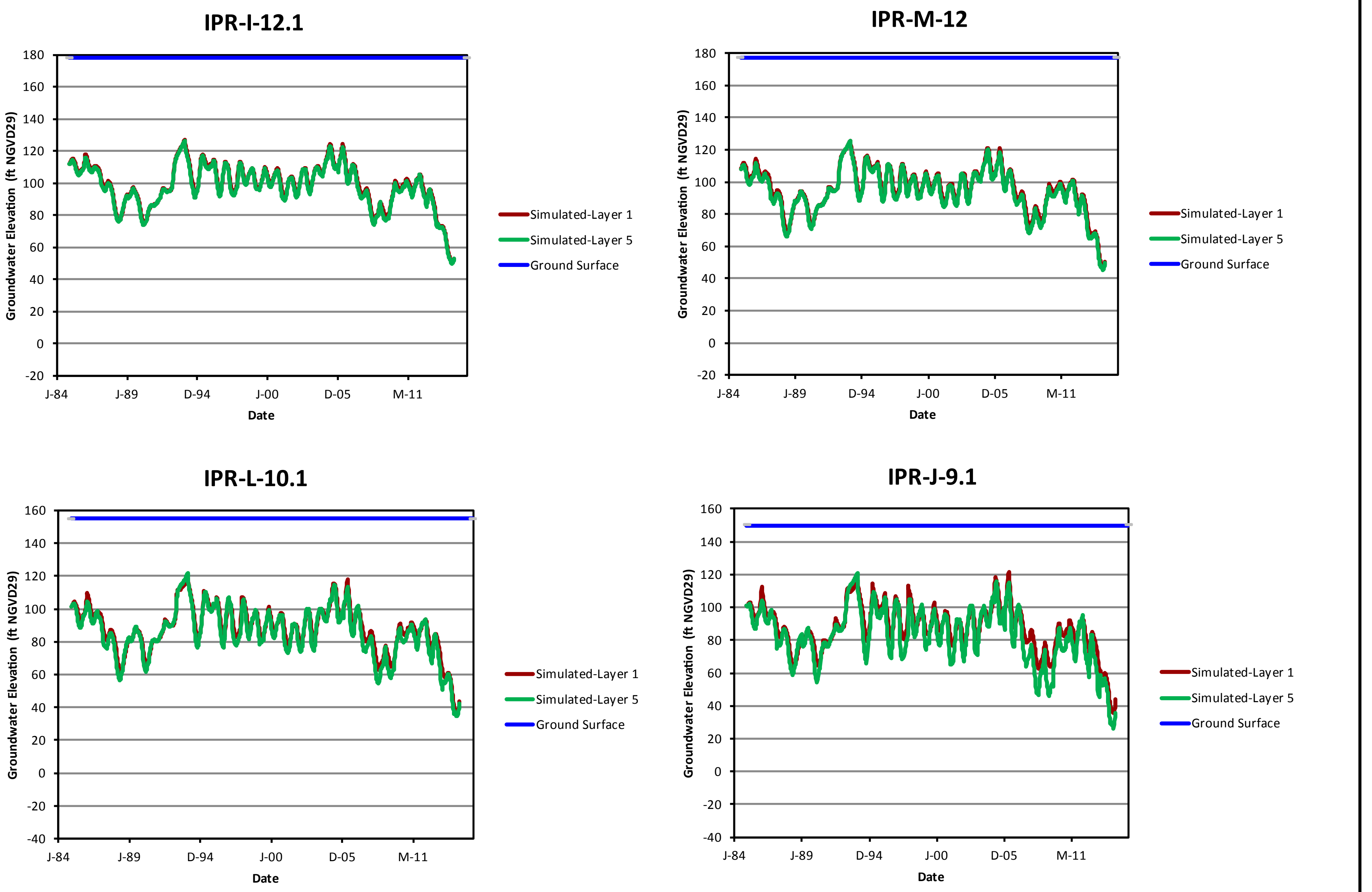
TODD GROUNDWATER

Figure 3
Comparison of WEAP Allocations for Los Gatos Ponds IPR Recharge under Scenarios 2 and 5



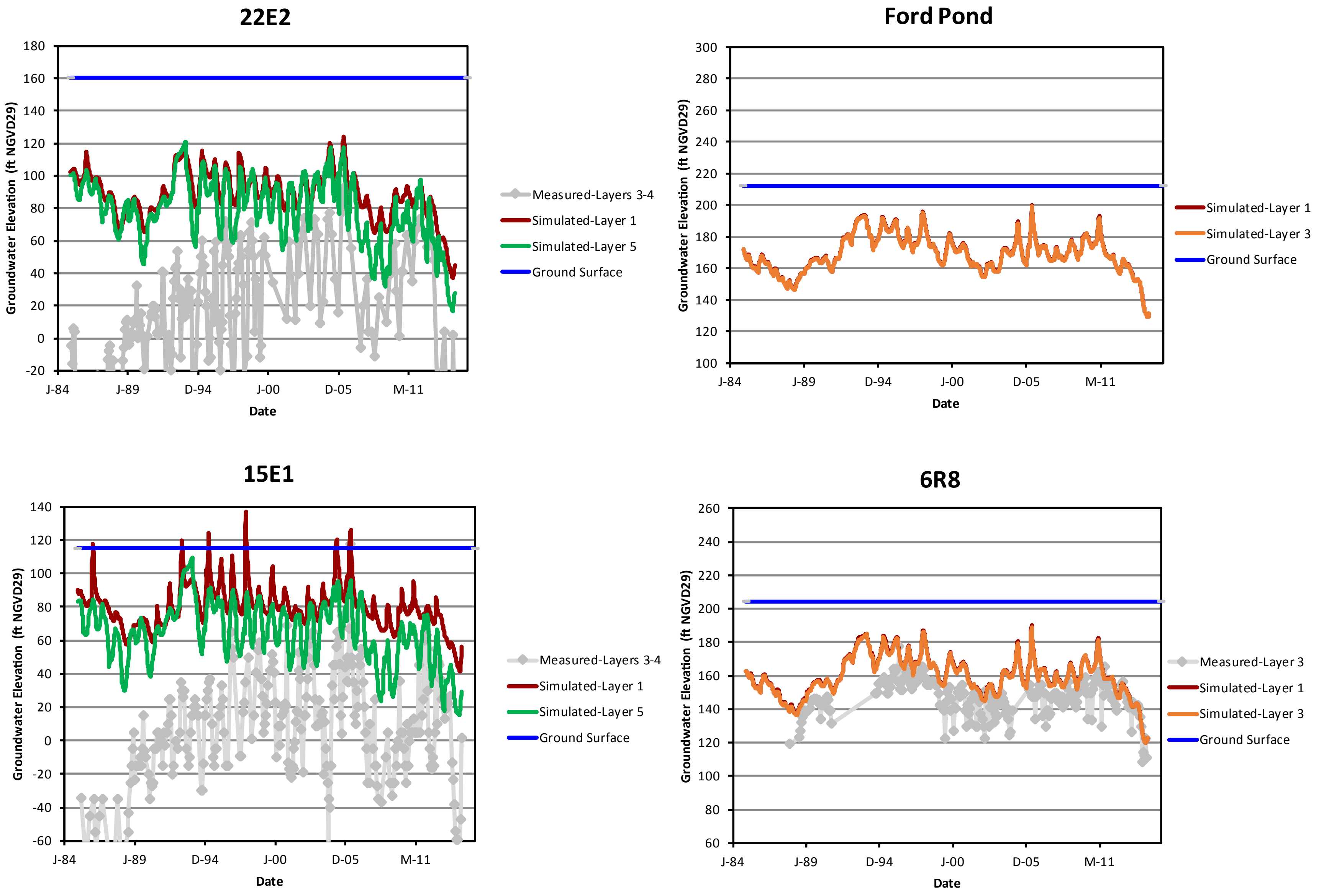
TODD
GROUNDWATER

Figure 4a
Hydrographs Simulated Water Levels near IPR Sites under Scenario 1 (No Purified Water Recharge)



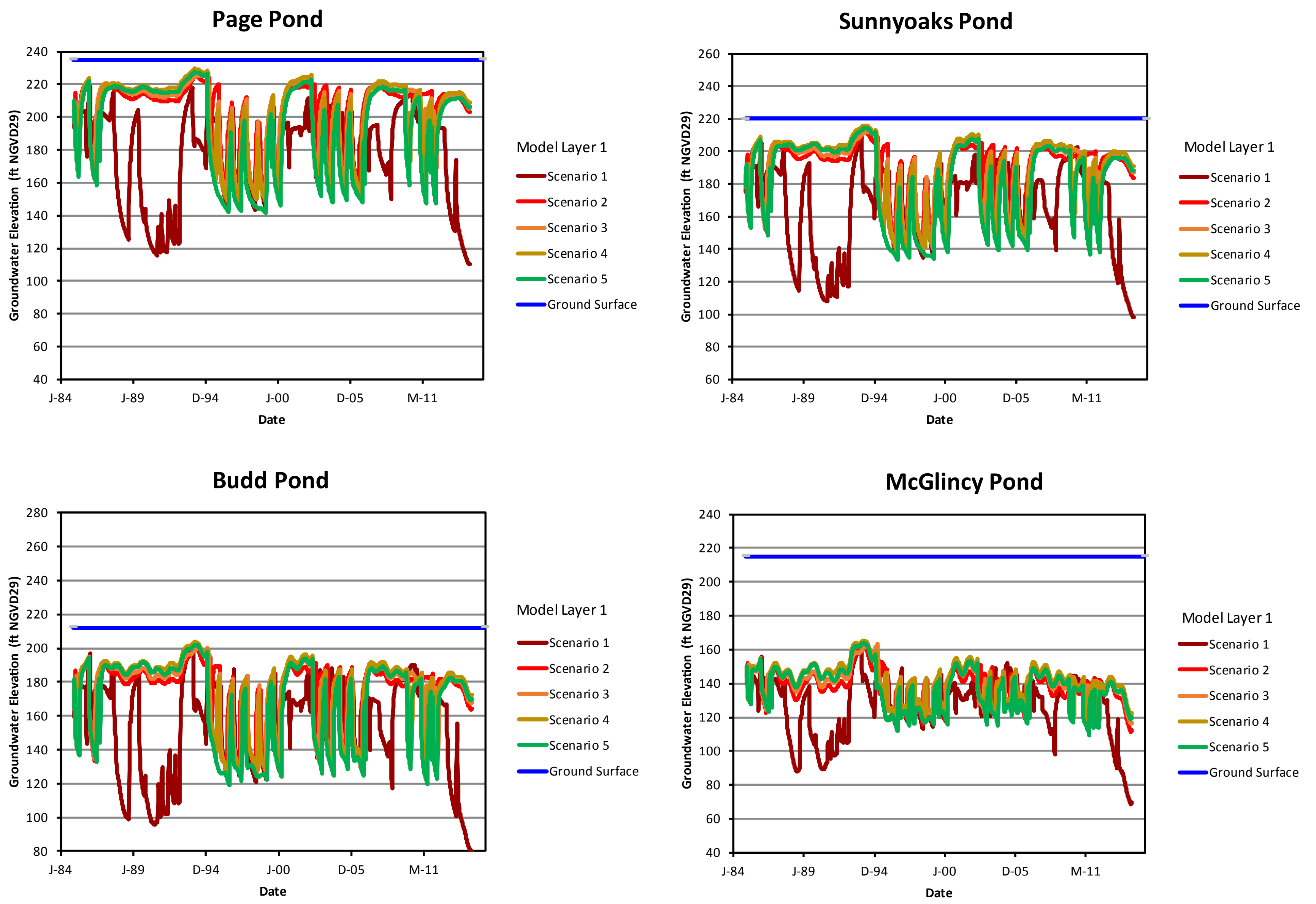
TODD GROUNDWATER

Figure 4b
Hydrographs Simulated Water Levels near IPR Sites under Scenario 1 (No Purified Water Recharge)



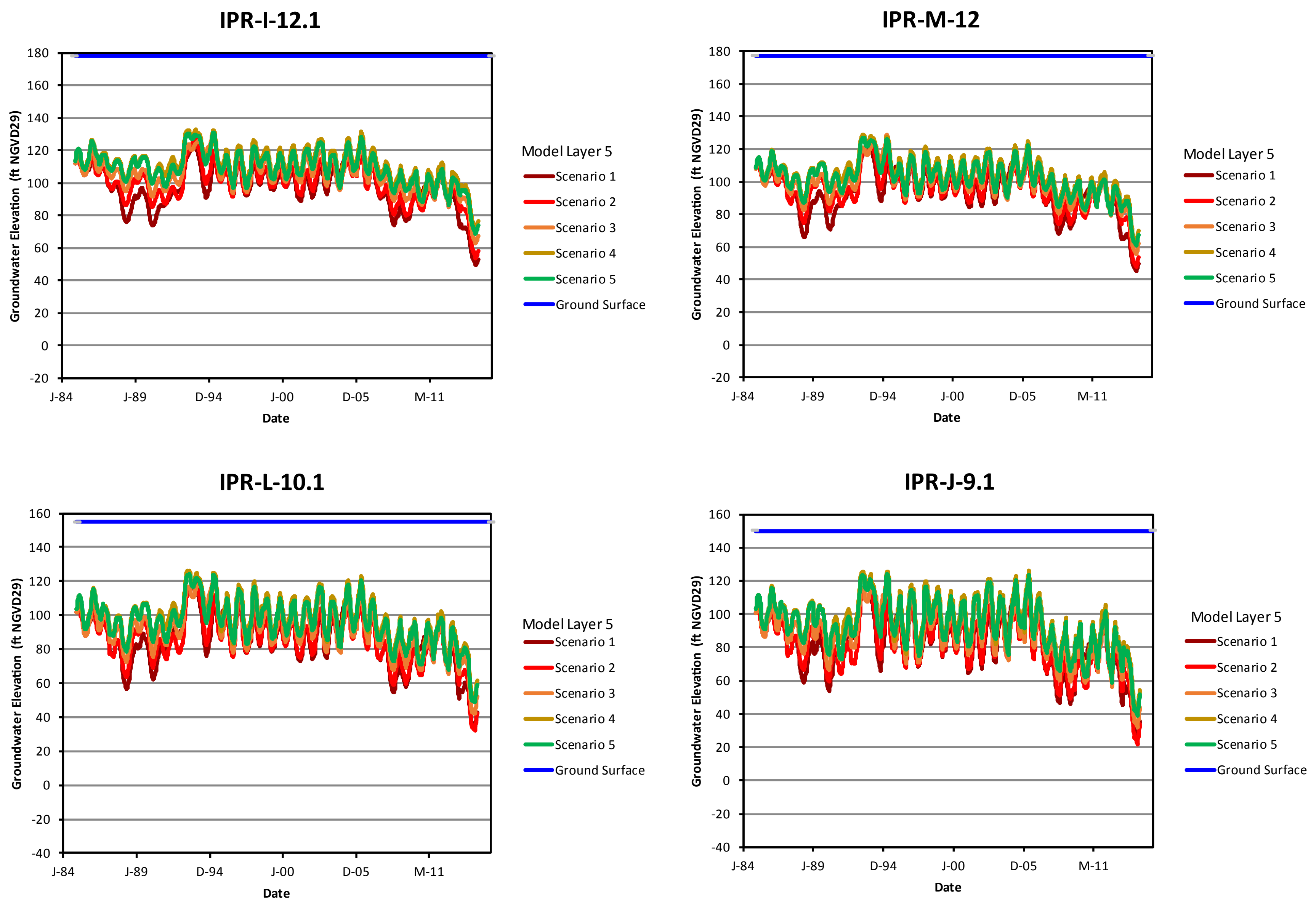
TODD
GROUNDWATER

Figure 4c
Hydrographs Simulated Water Levels near IPR Sites under Scenario 1
(No Purified Water Recharge)



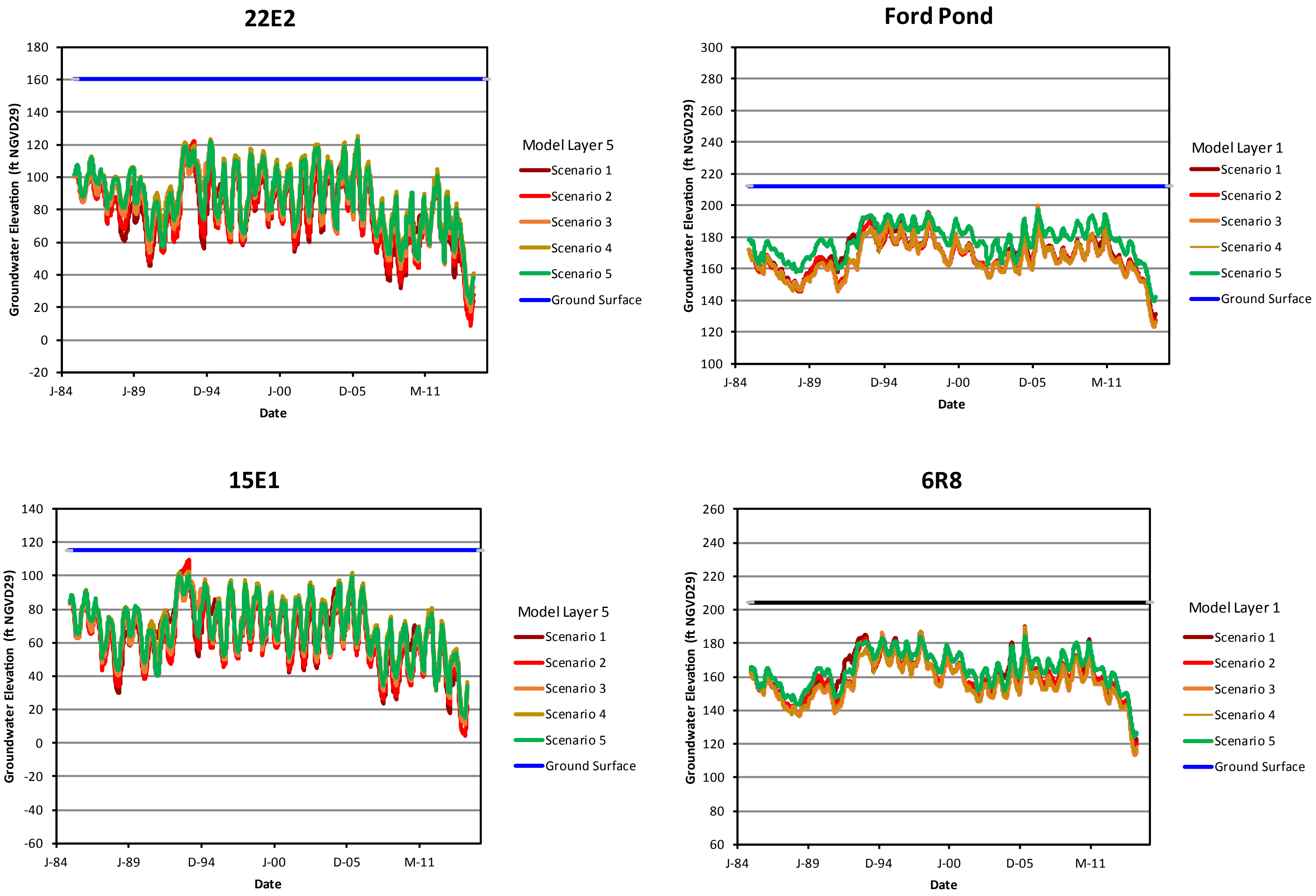
TODD GROUNDWATER

Figure 5a
Hydrographs of Simulated Water Levels near IPR Sites under Scenarios 1 through 5



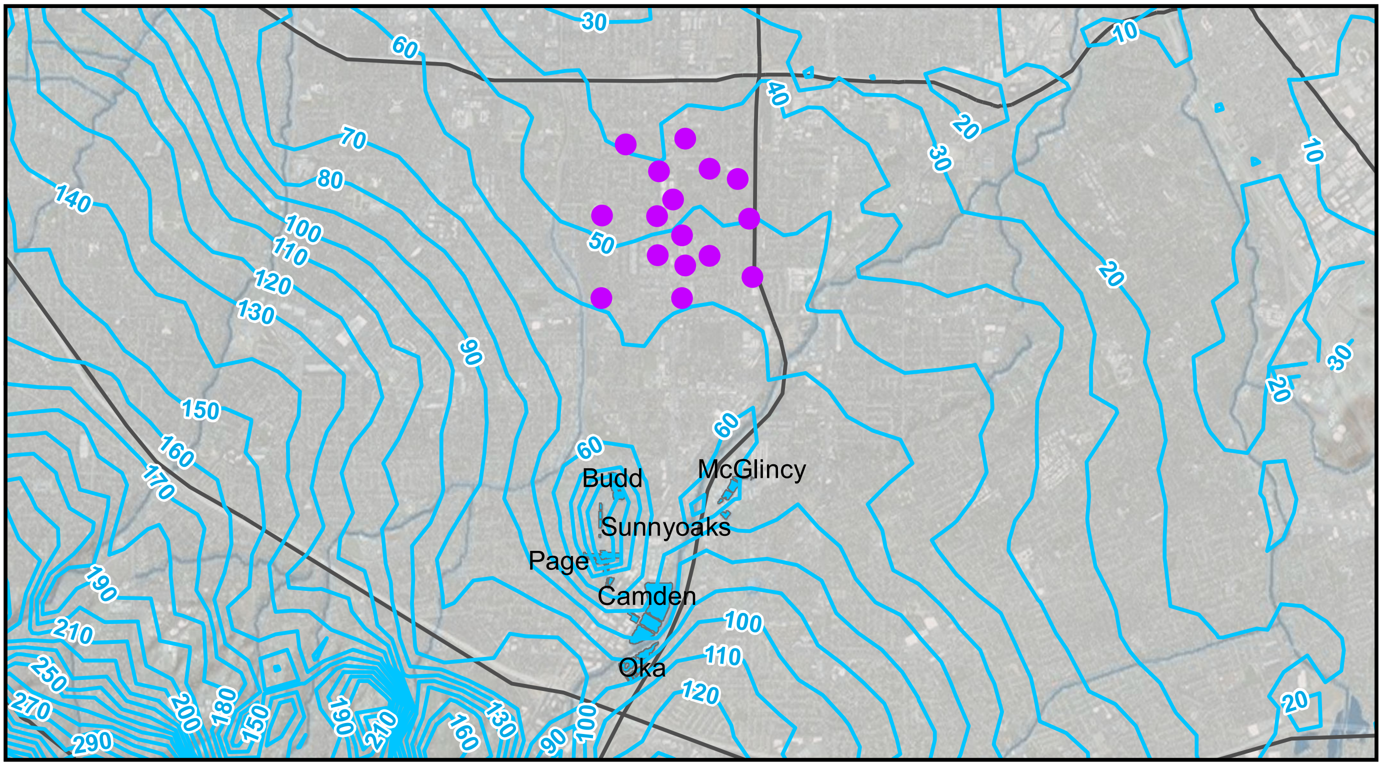
TODD GROUNDWATER

Figure 5b
Hydrographs of Simulated Water Levels near IPR Sites under Scenarios 1 through 5

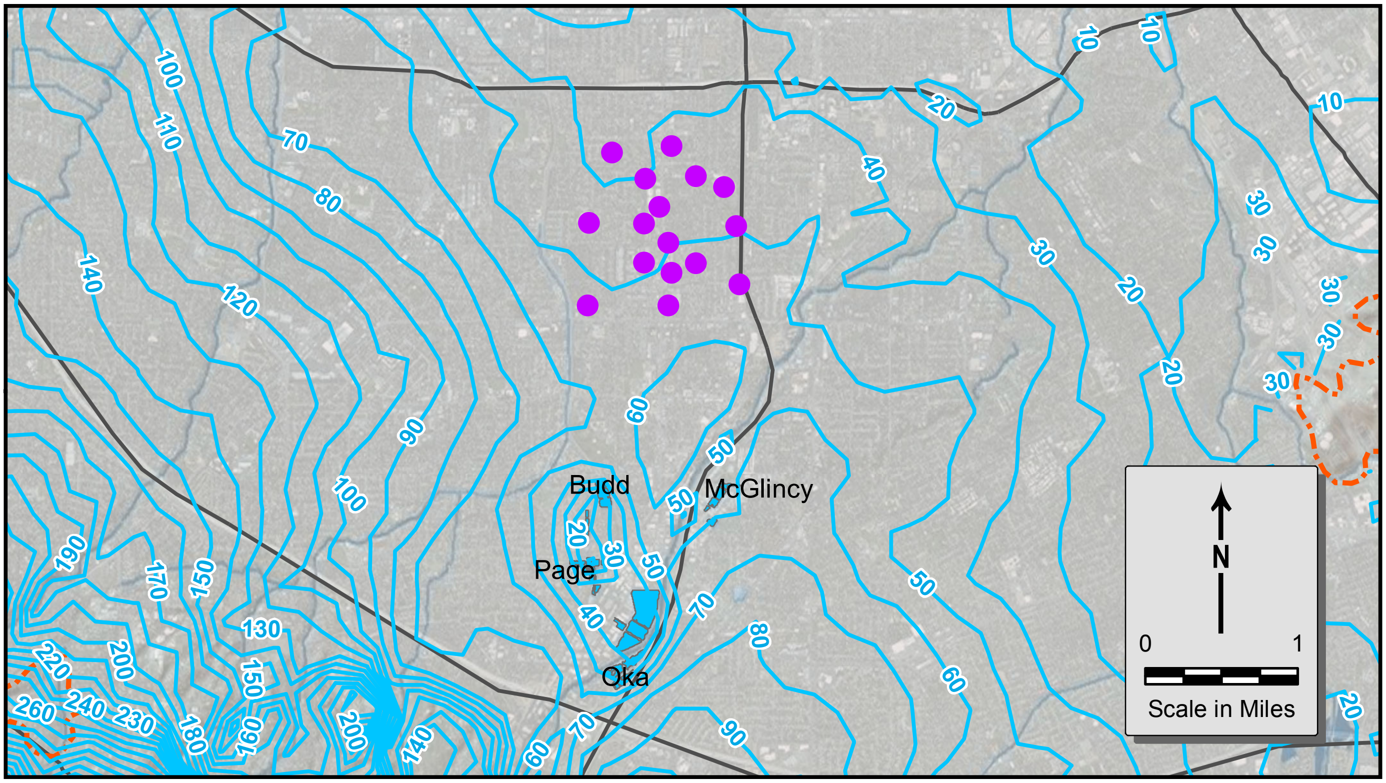


TODD GROUNDWATER

Figure 5c
Hydrographs of Simulated Water Levels near IPR Sites under Scenarios 1 through 5



6A. Scenario 1, Layer 1



6B. Scenario 5, Layer 1

Legend

● IPR Well Group 3

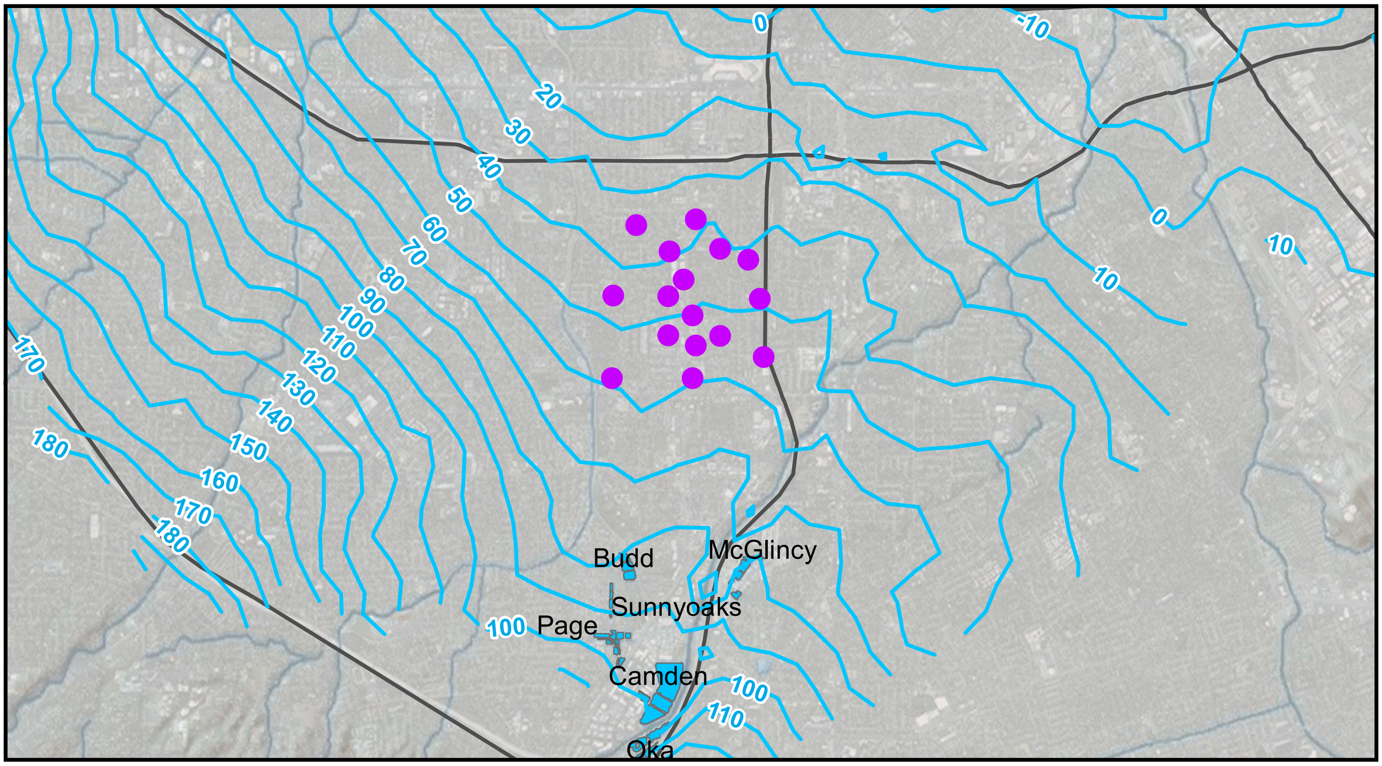
— Depth to Groundwater (feet)

▬ IPR Percolation Ponds

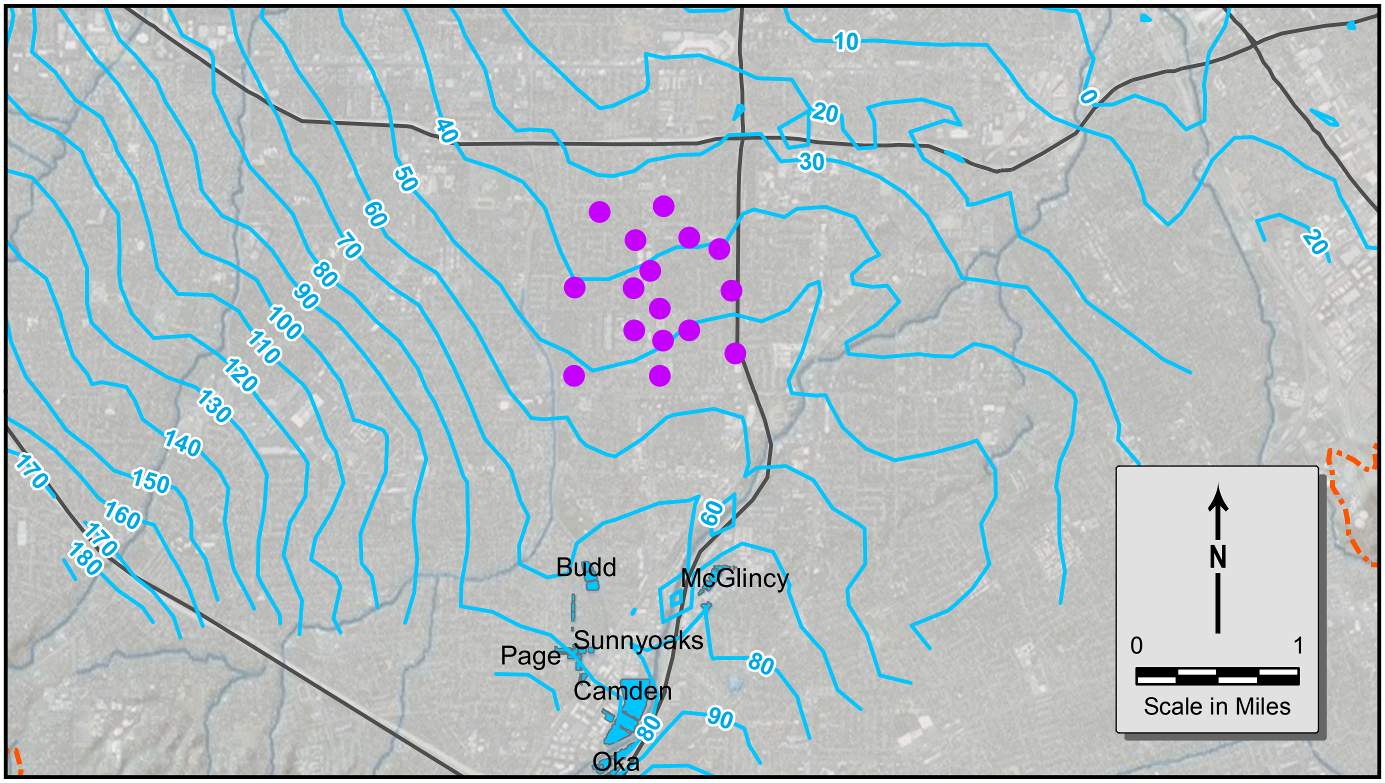
IPR - Indirect potable reuse

TODD GROUNDWATER

Figure 6
Simulated Depth to Water in December 1993 in Model Layer 1, Southwest Subbasin Area



7A. Scenario 1, Layer 5



7B. Scenario 5, Layer 5

Legend

● IPR Well Group 3

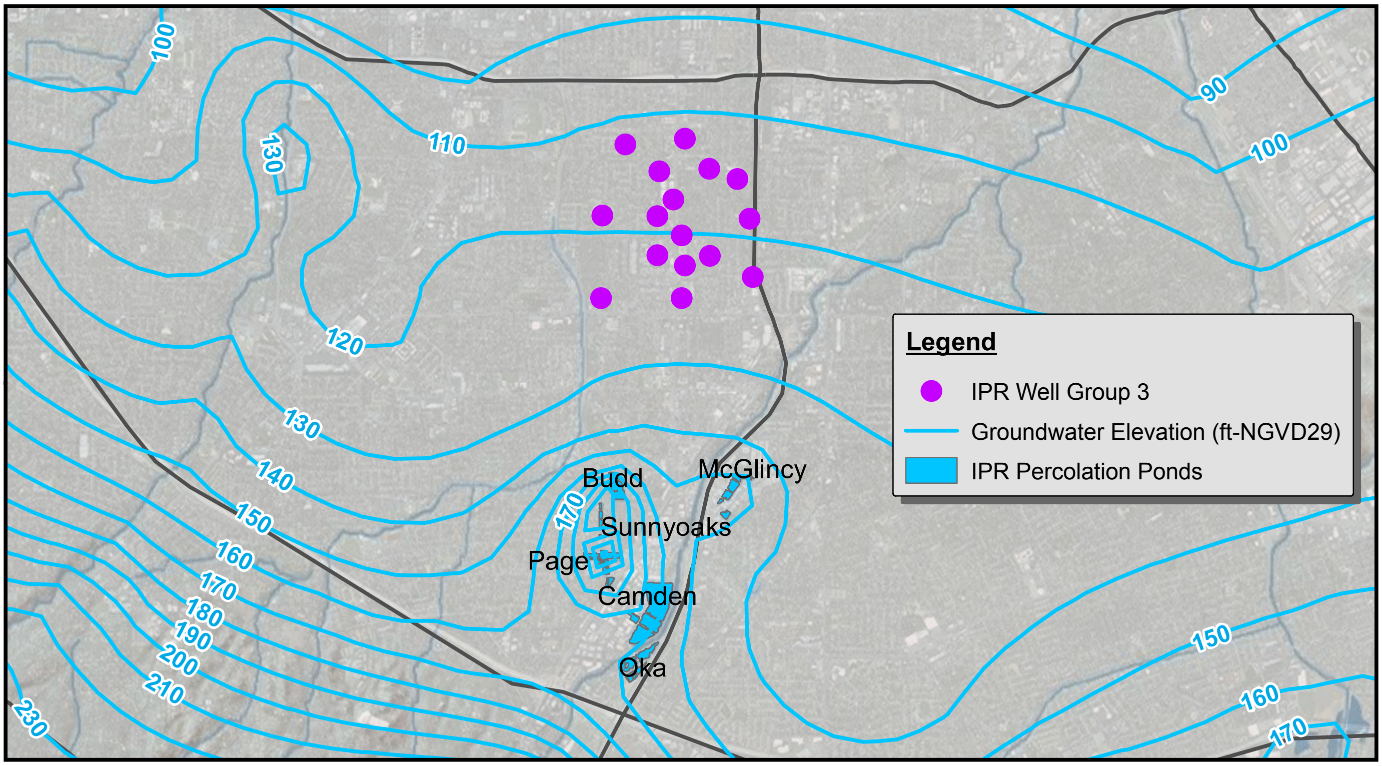
— Depth to Groundwater (feet)

🟦 IPR Percolation Ponds

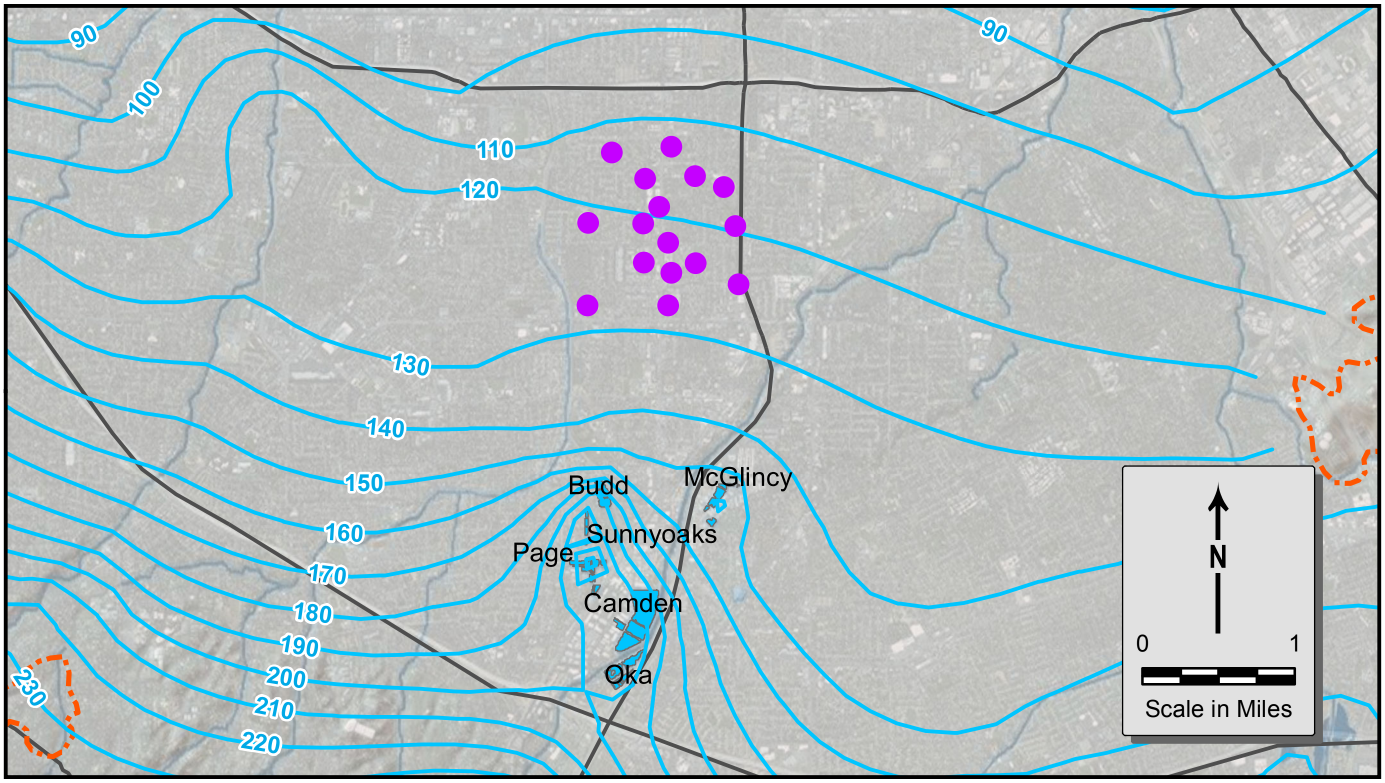
IPR - Indirect potable reuse

TODD GROUNDWATER

Figure 7
Simulated Depth to Water in December 1993 in Model Layer 5, Southwest Subbasin Area



8A. Scenario 1, Layer 1, December 1993

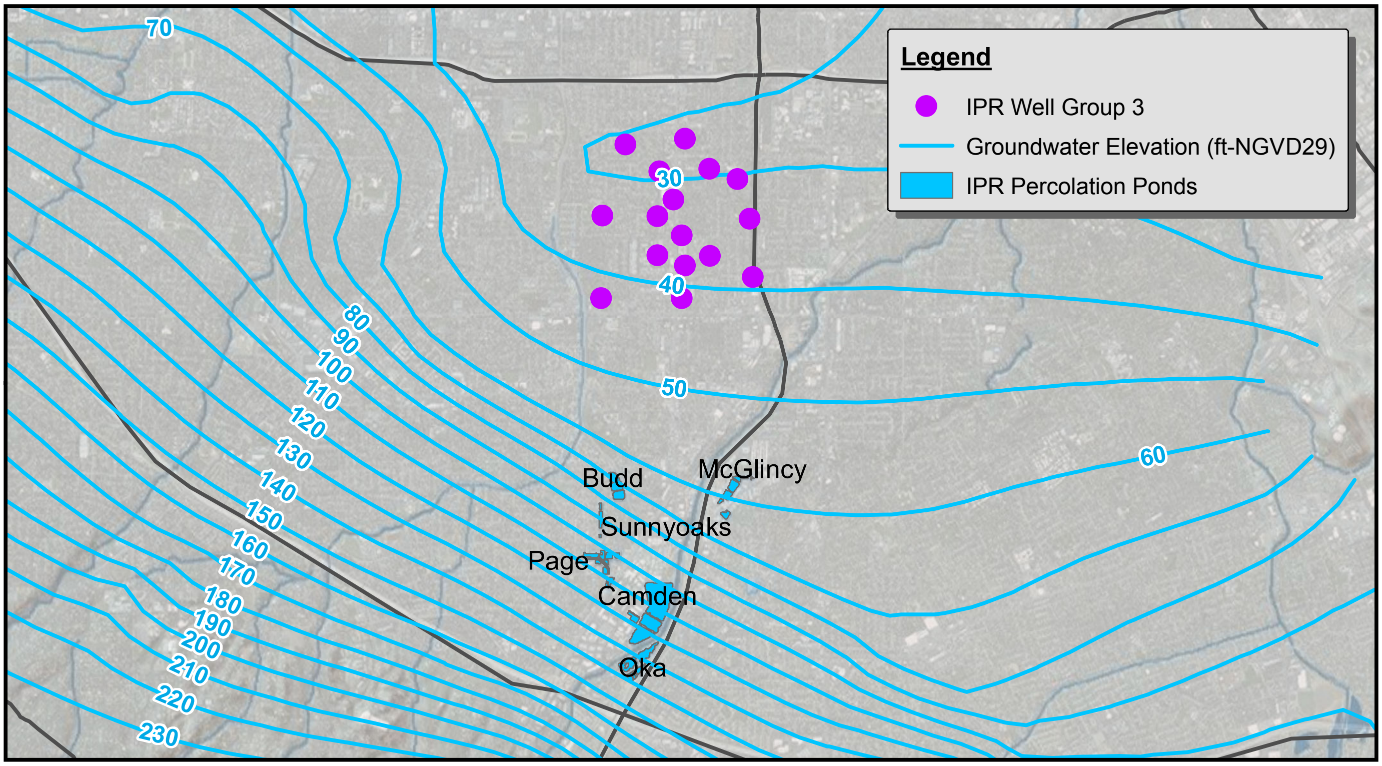


8B. Scenario 5, Layer 1, December 1993

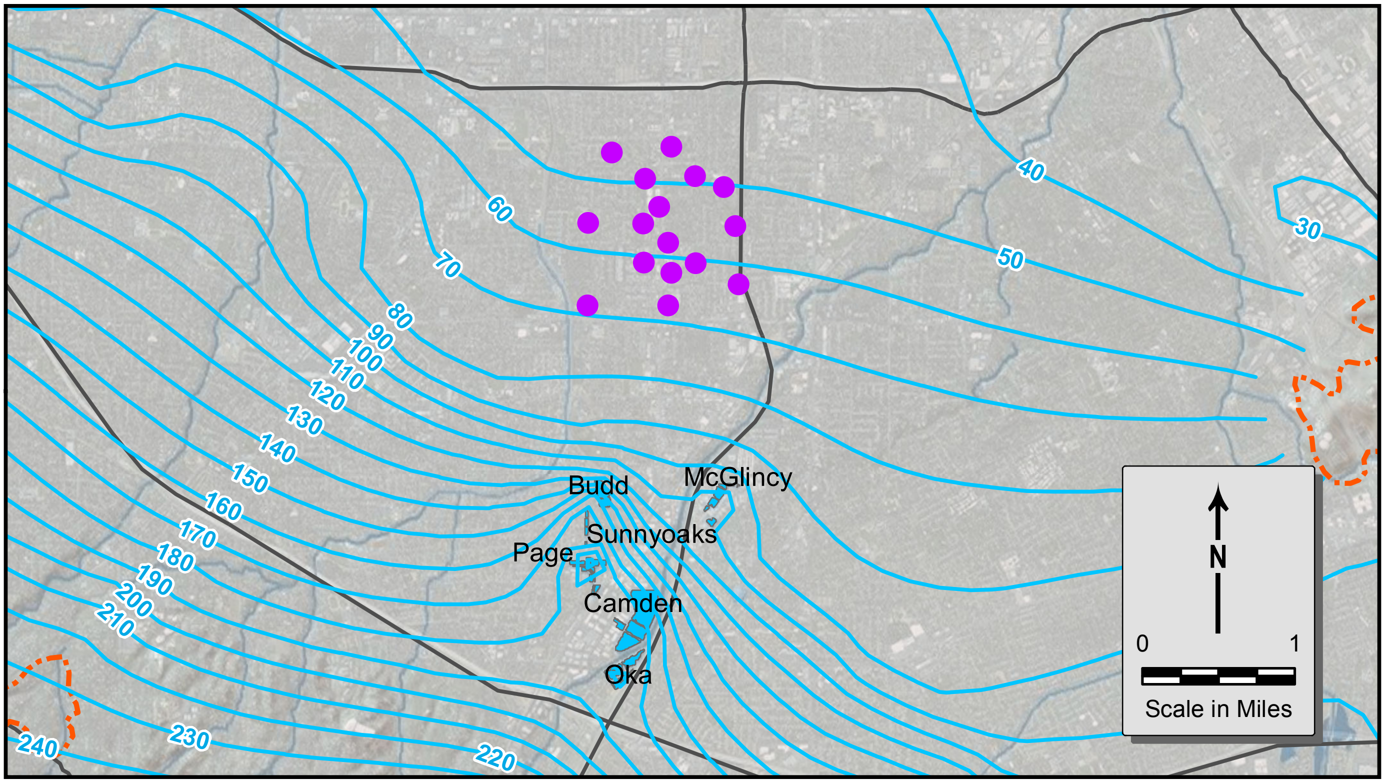
IPR - Indirect potable reuse
ft-NGVD29 - feet National Geodetic Vertical Datum of 1929

TODD GROUNDWATER

Figure 8
Simulated Groundwater Elevation in December 1993 in Model Layer 1, Southwest Subbasin Area



9A. Scenario 1, Layer 1, November 2014

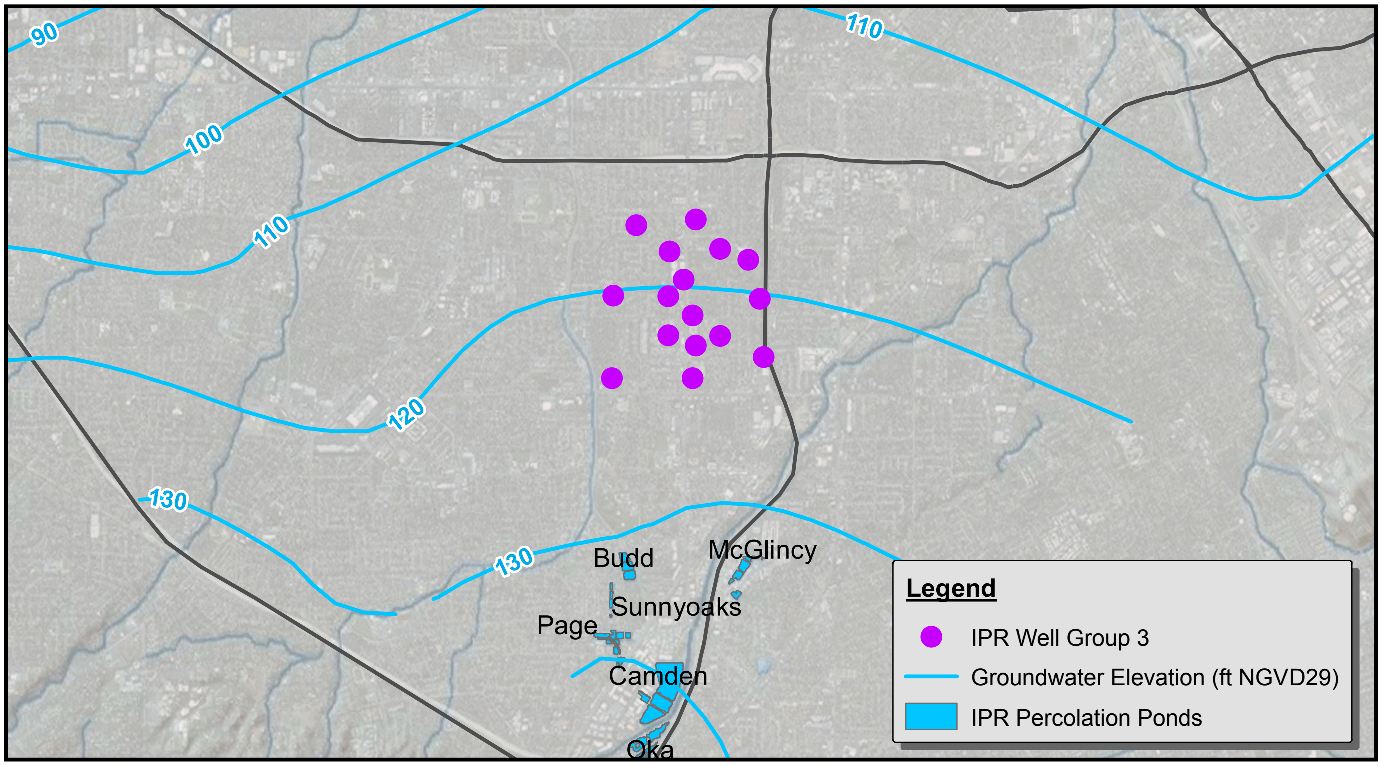


9B. Scenario 5, Layer 1, November 2014

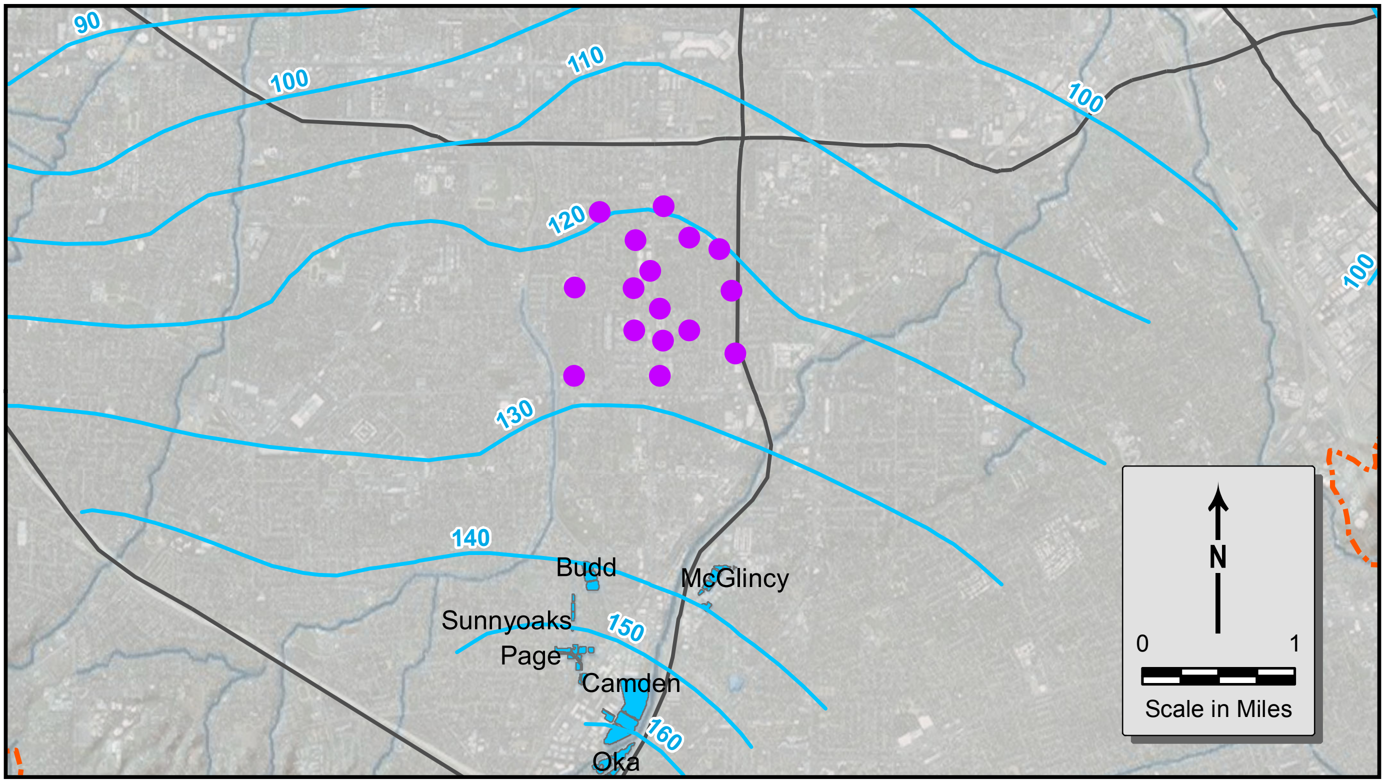
IPR - Indirect potable reuse
ft-NGVD29 - feet National Geodetic
Vertical Datum of 1929

TODD GROUNDWATER

Figure 9
Simulated Groundwater Elevation in November 2014 in Model Layer 1, Southwest Subbasin Area



10A. Scenario 1, Layer 5

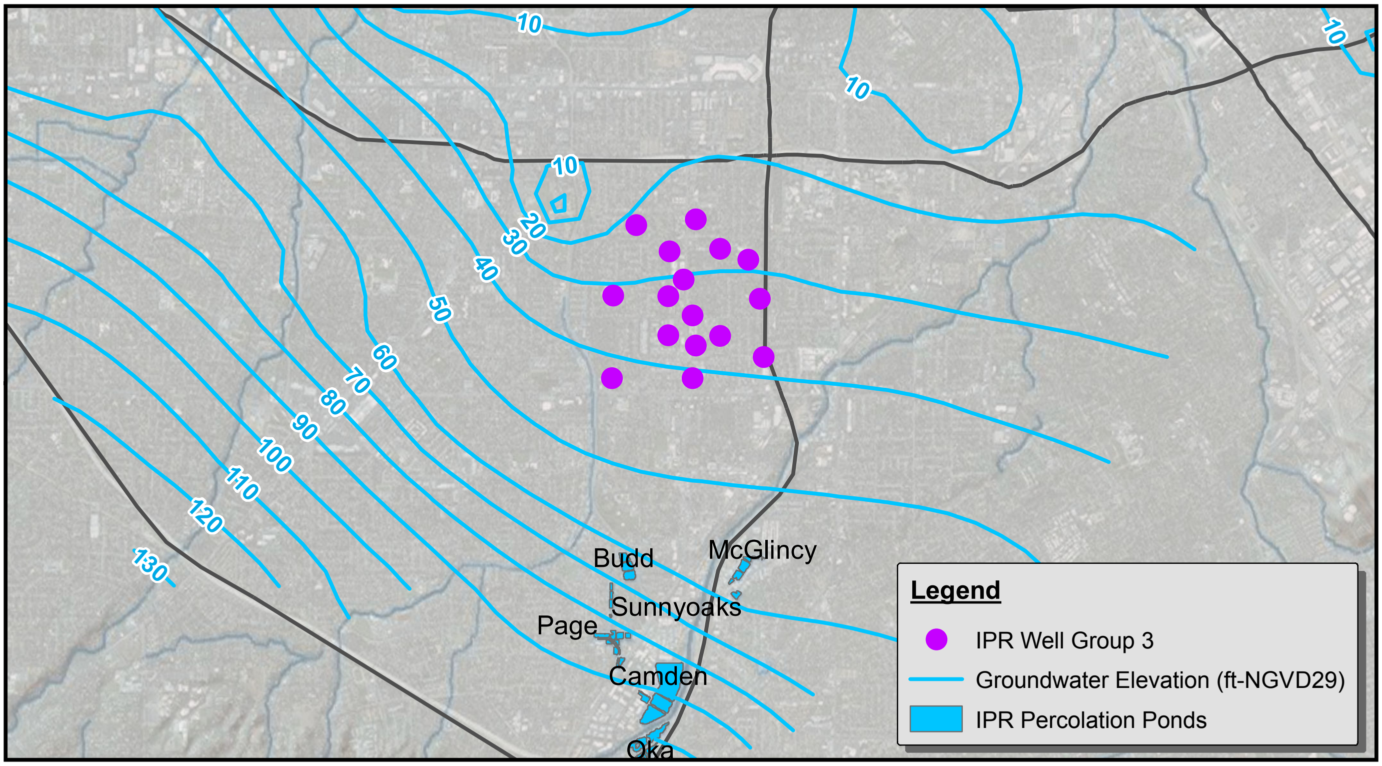


10B. Scenario 5, Layer 5

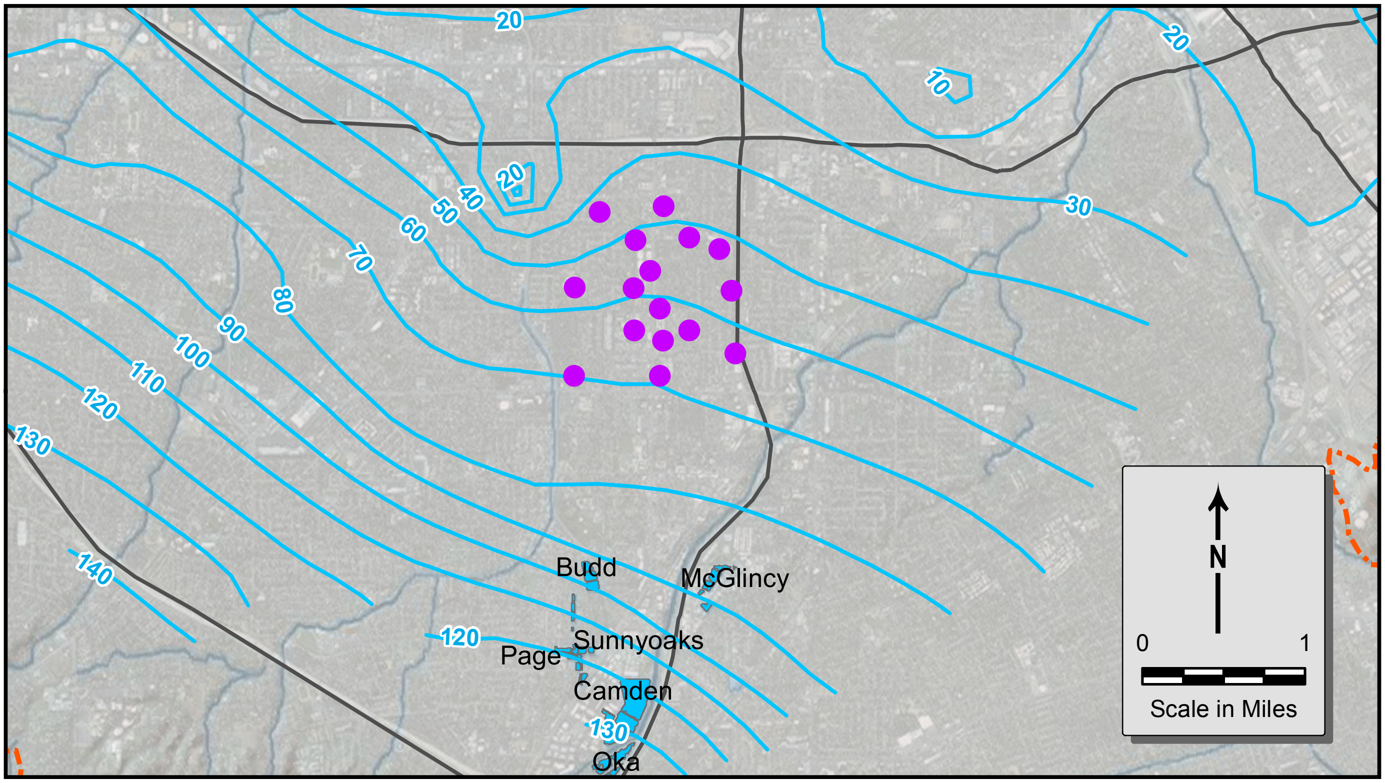
IPR - Indirect potable reuse
ft-NGVD29 - feet National Geodetic
Vertical Datum of 1929

TODD GROUNDWATER

Figure 10
Simulated Groundwater Elevation in December 1993 in Model Layer 5, Southwest Subbasin Area



11A. Scenario 1, Layer 5



11B. Scenario 5, Layer 5

IPR - Indirect potable reuse
ft-NGVD29 - feet National Geodetic
Vertical Datum of 1929

TODD GROUNDWATER

Figure 11
Simulated Groundwater Elevation in November 2014 in Model Layer 5, Southwest Subbasin Area

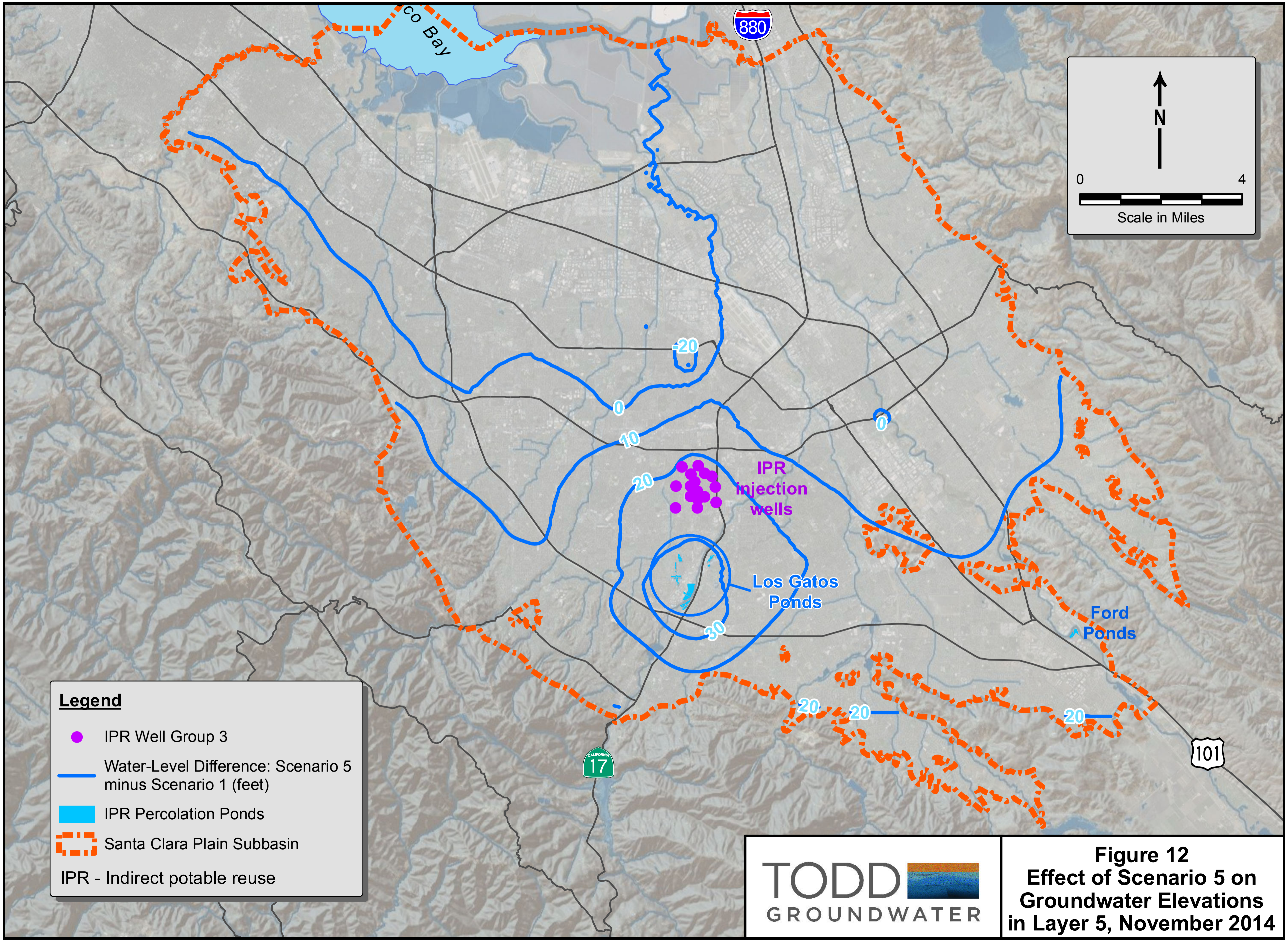
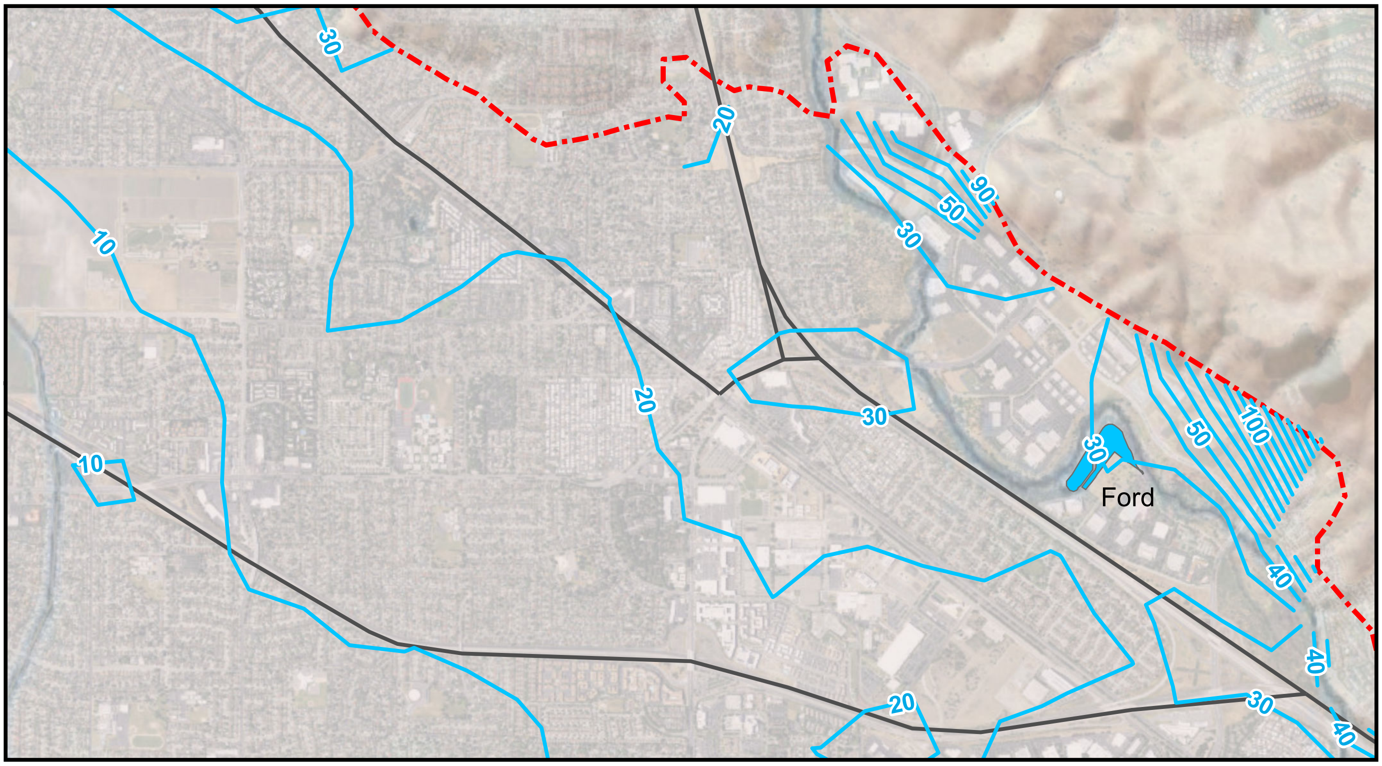
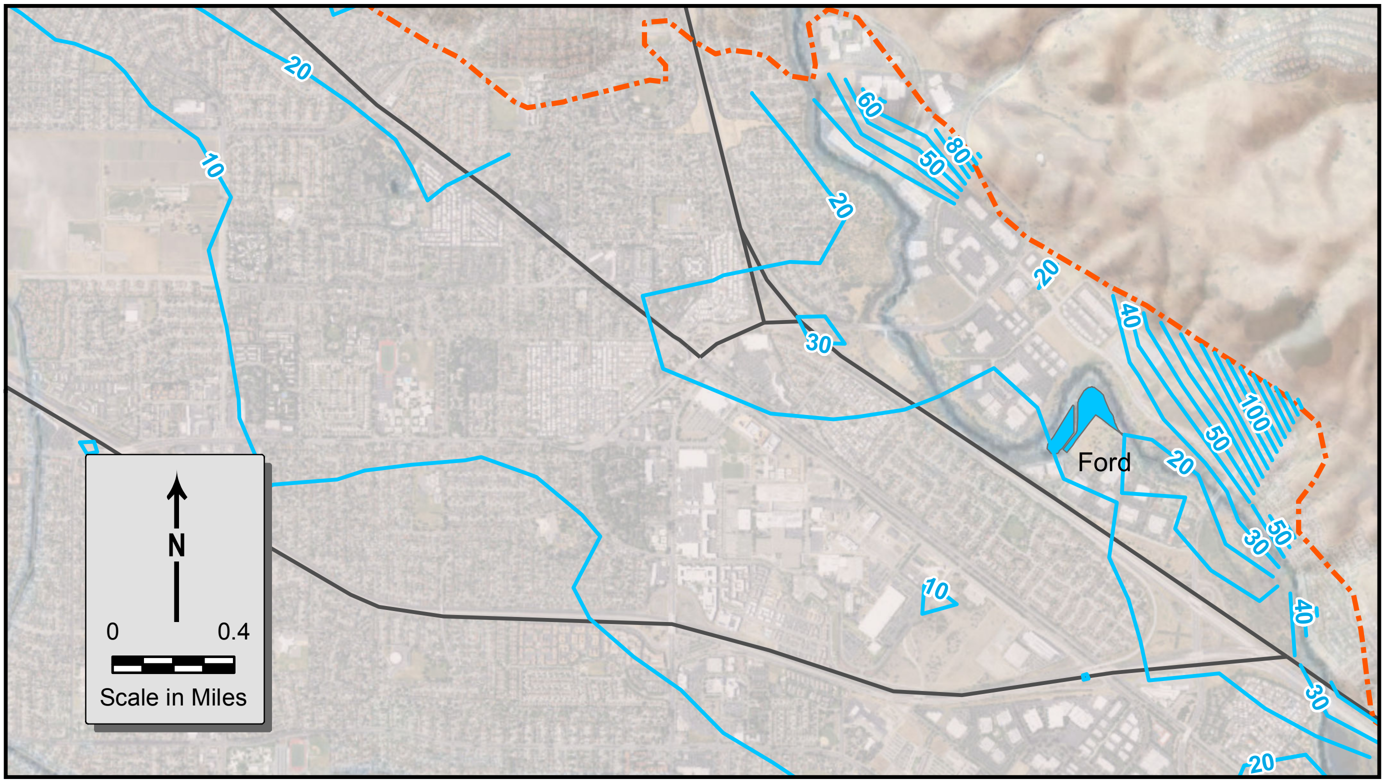


Figure 12
Effect of Scenario 5 on
Groundwater Elevations
in Layer 5, November 2014



13A. Scenario 1, Layer 1



13B. Scenario 5, Layer 1

Legend

● IPR Well Group 3

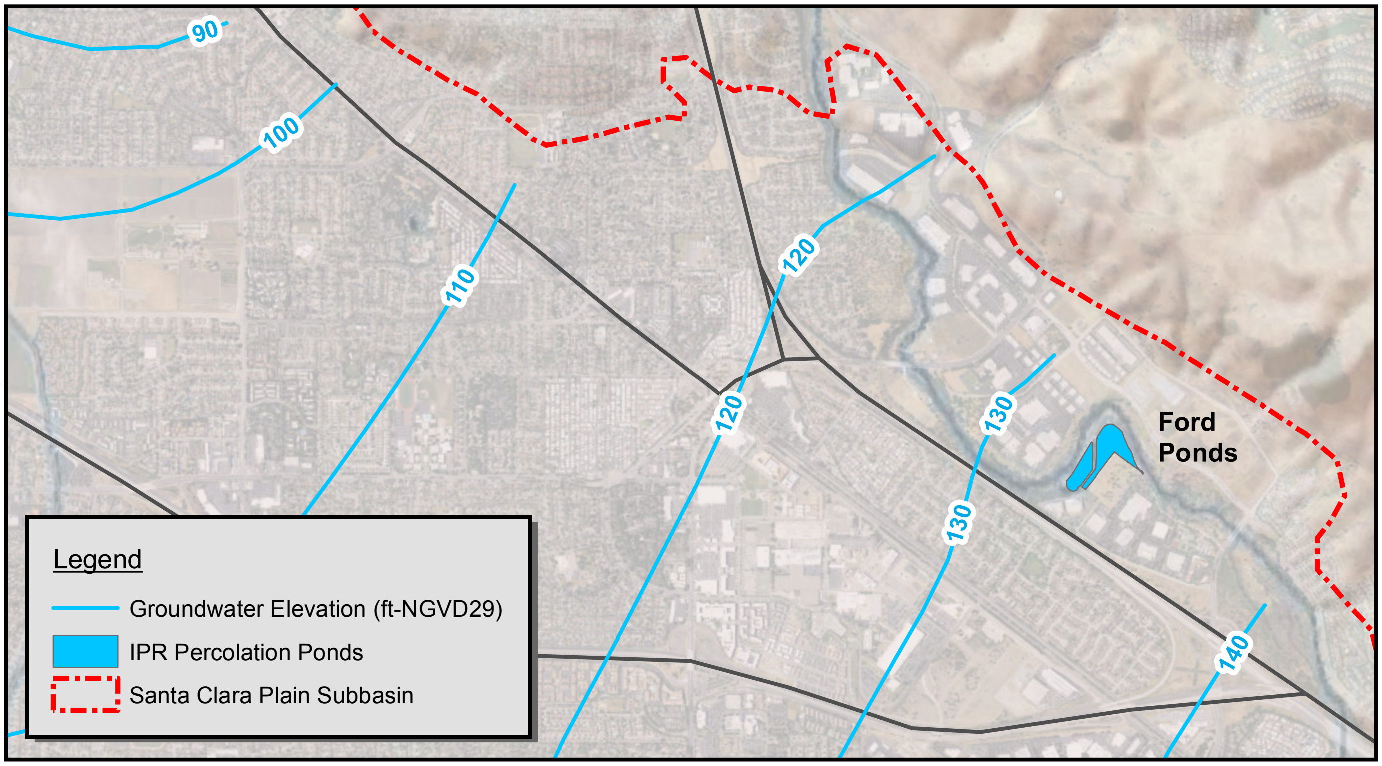
— Depth to Water (feet)

▆ IPR Percolation Ponds

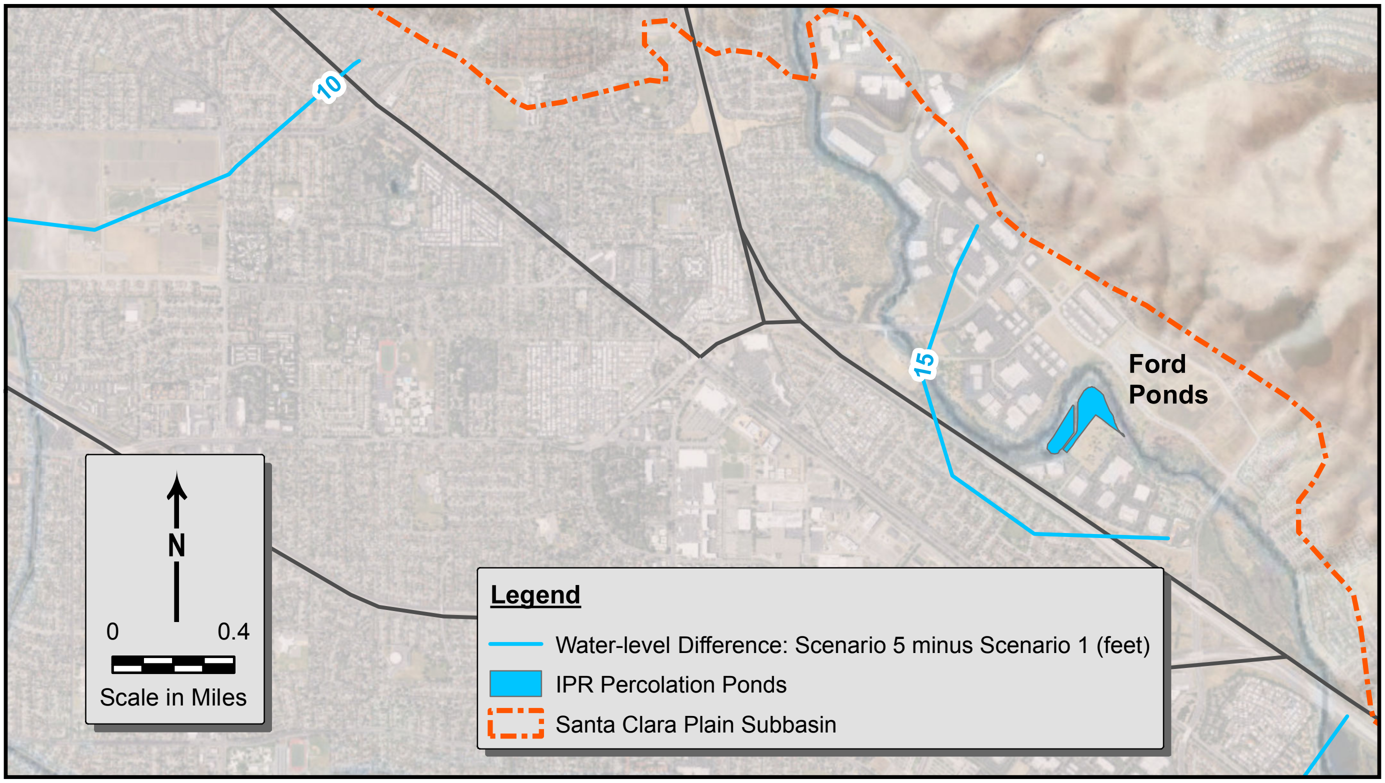
IPR - Indirect potable reuse

TODD GROUNDWATER

Figure 13
Simulated Depth to Water in December 1993 in Model Layer 1, Ford Ponds Area



14A. Scenario 5, Layer 1

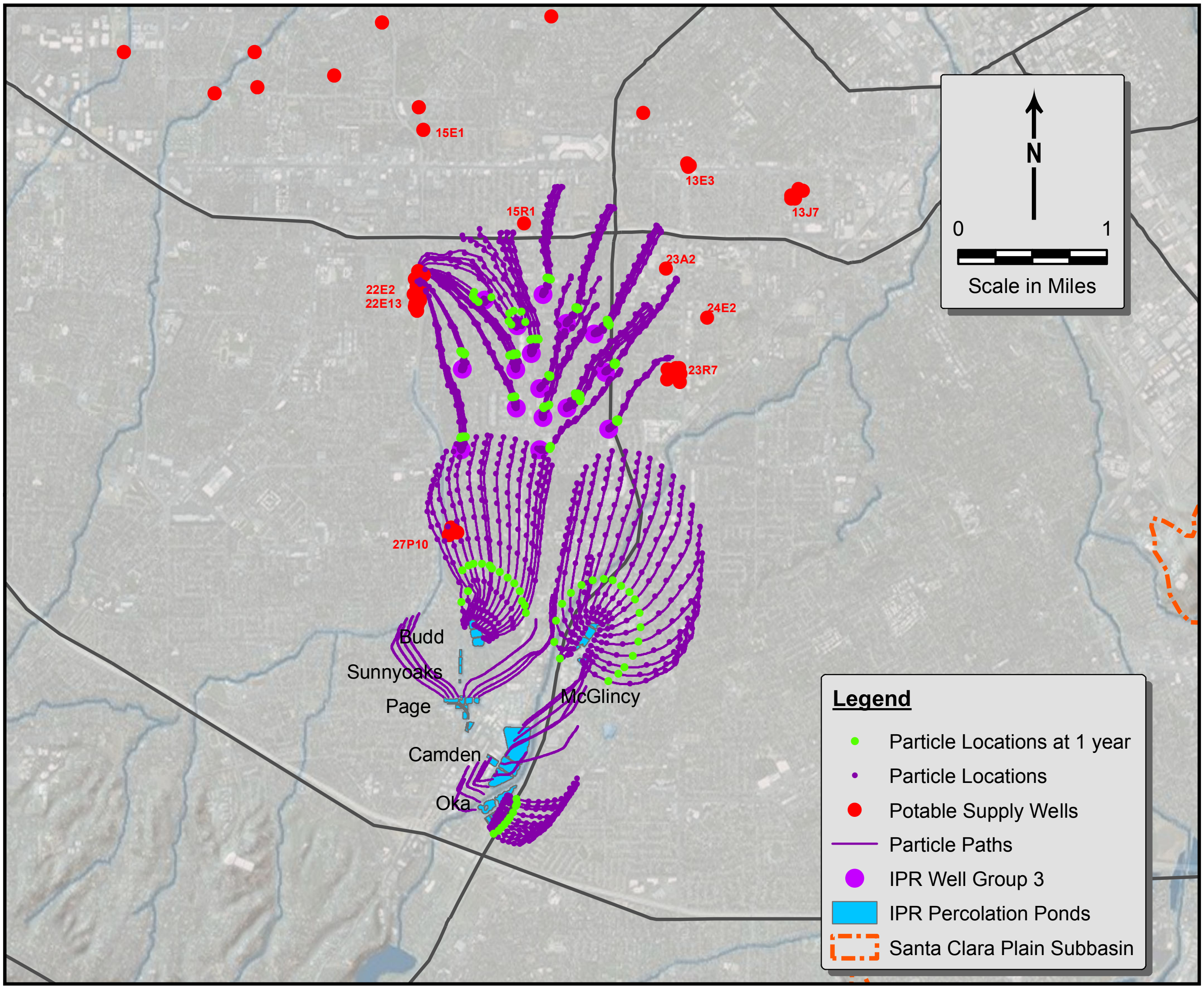

10
15
Ford Ponds
N
0
0.4
Scale in Miles
Legend
Water-level Difference: Scenario 5 minus Scenario 1 (feet)
IPR Percolation Ponds
Santa Clara Plain Subbasin

14B. Scenario 5 minus Scenario 1, Layer 1

IPR - Indirect potable reuse
ft-NGVD29 - feet National Geodetic
Vertical Datum of 1929

TODD GROUNDWATER

Figure 14
Groundwater Elevations in Ford Pond 5 Area, November 2014

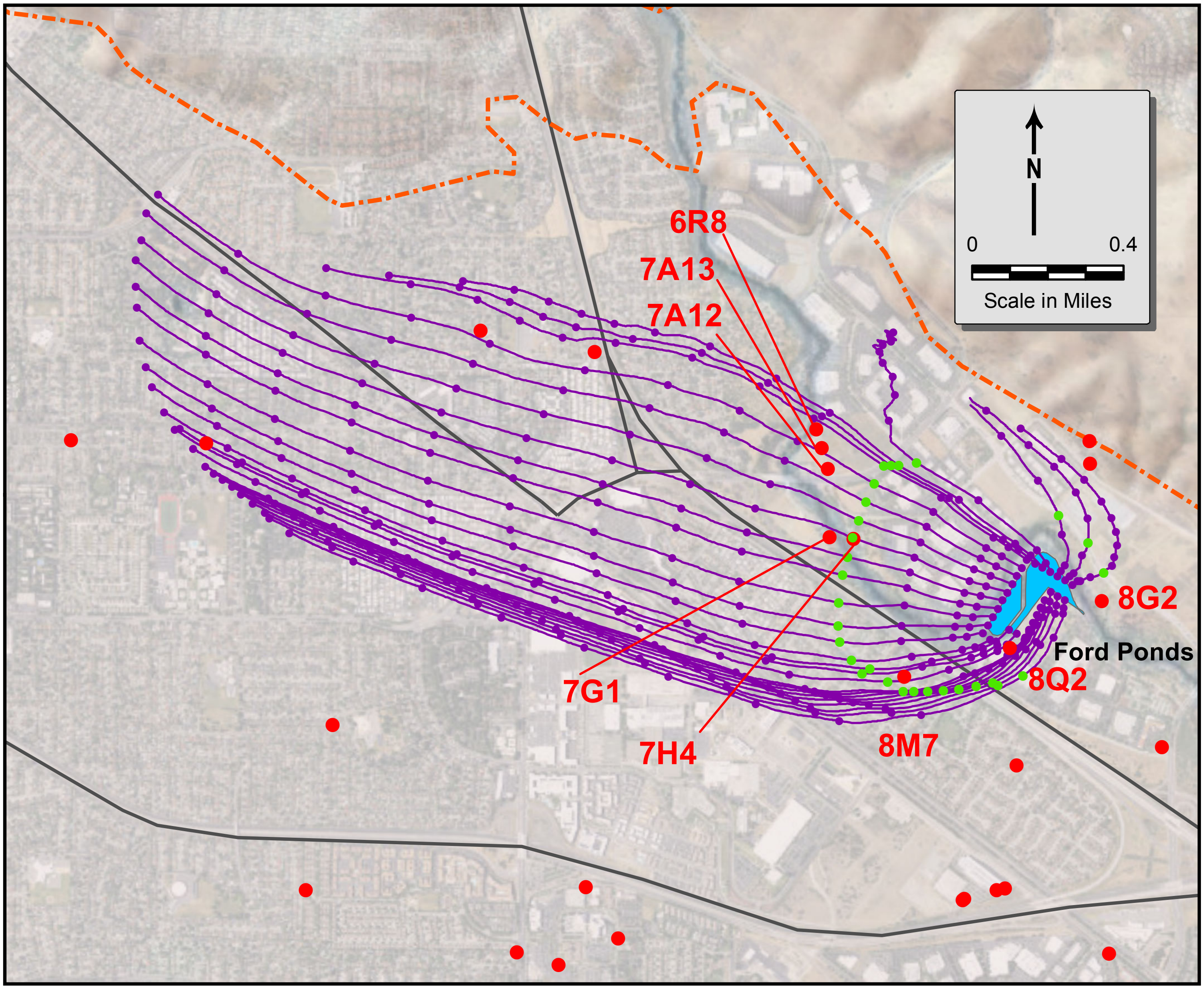


Particle locations shown
for 0, 1, 2, 6,12 months
and 2 through 10 years
of travel.

IPR - Indirect potable reuse

TODD
GROUNDWATER

Figure 15
Groundwater Travel
Times in Southwest Subbasin
Area, Scenario 5



Legend

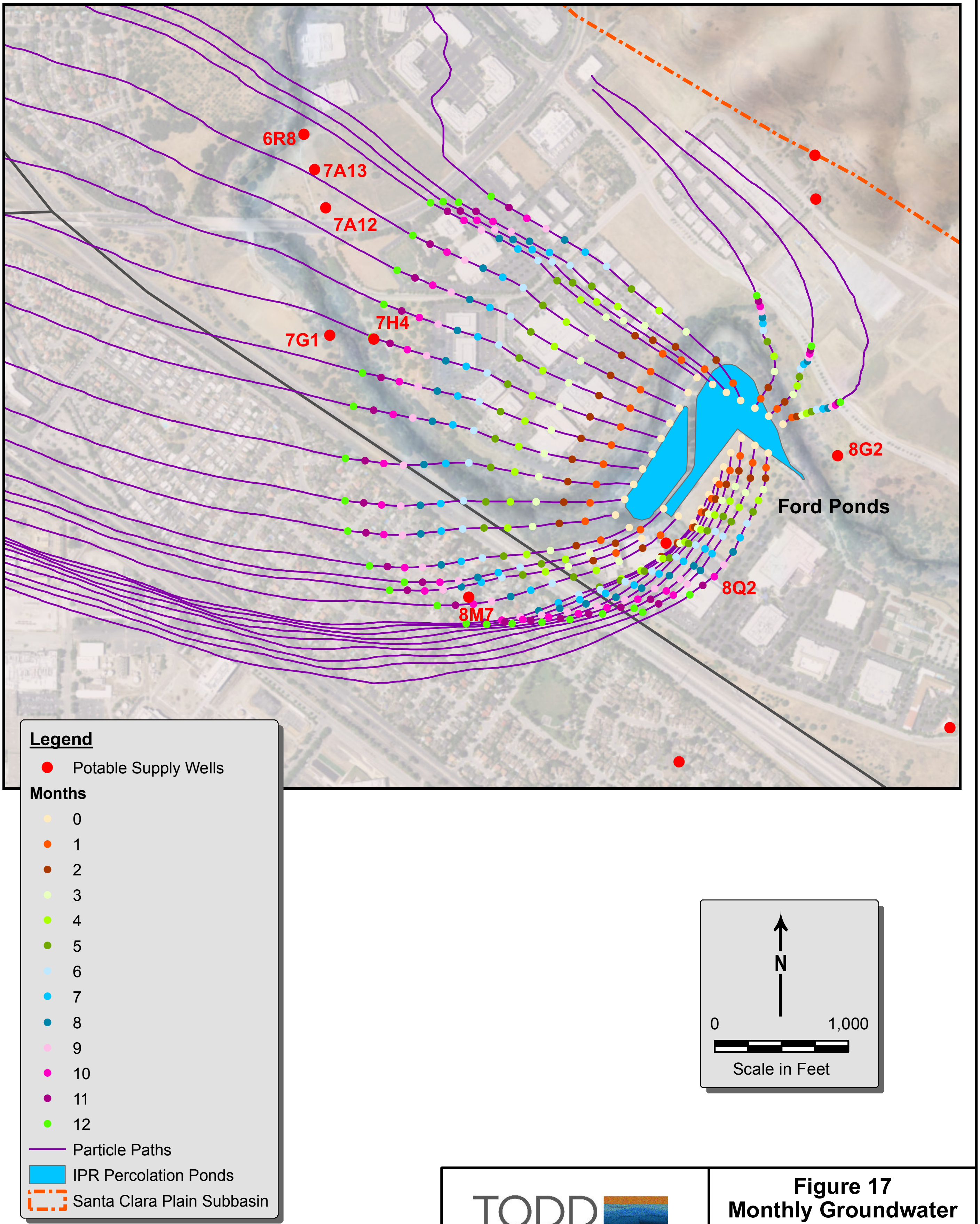
- ● Particle Locations at 1 year
- ● Potable Supply Wells
- ● Particle Locations
- — Particle Paths
- 🟦 IPR Percolation Ponds
- ▭ Santa Clara Plain Subbasin

Particle locations shown for 0, 1, 2, 6,12 months and 2 through 10 years of travel.

IPR - Indirect potable reuse

TODD GROUNDWATER

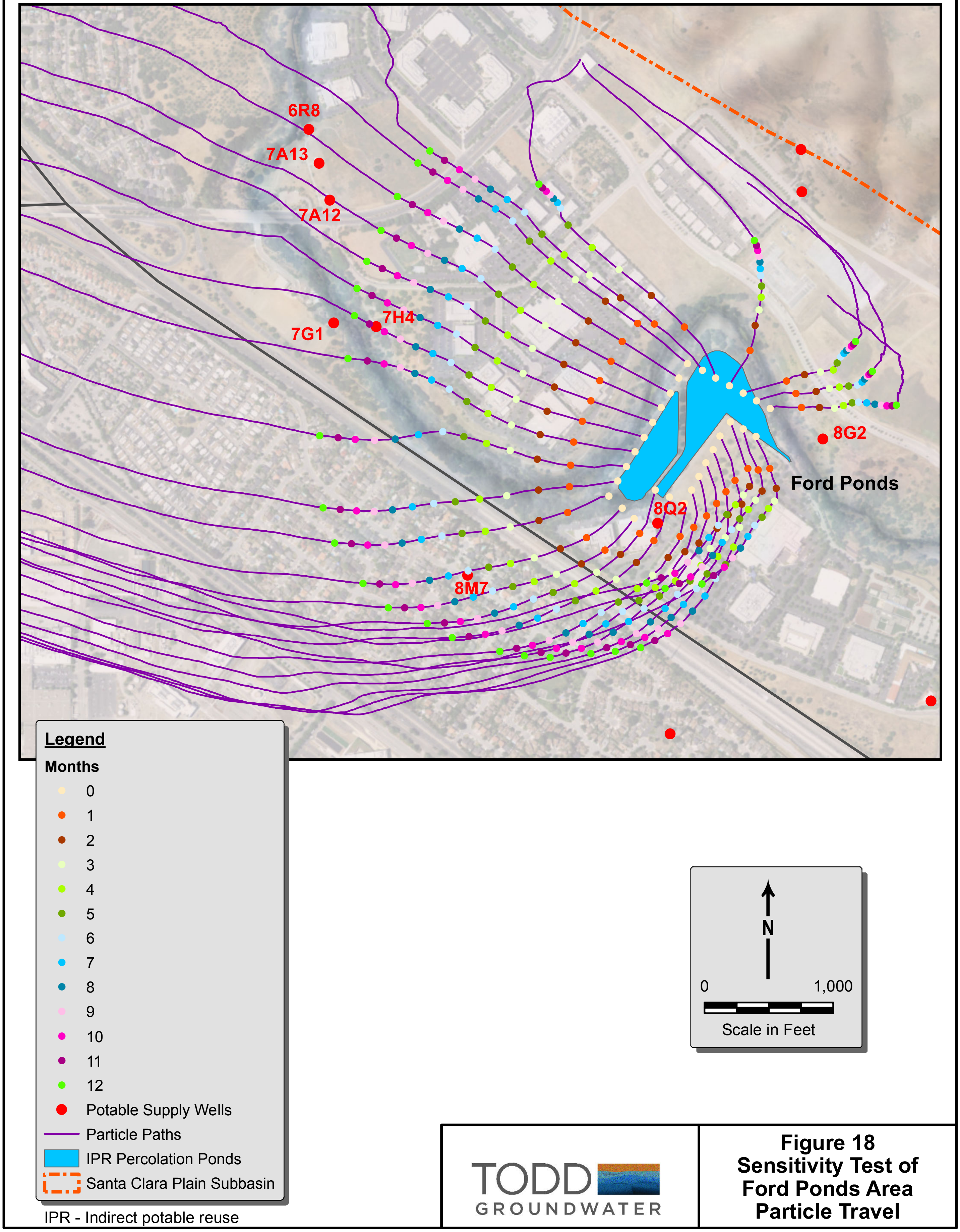
Figure 16
Groundwater Travel Times in Ford Ponds Area, Scenario 5



IPR - Indirect potable reuse

TODD GROUNDWATER

Figure 17
Monthly Groundwater Travel Times in Ford Ponds Area, Scenario 5

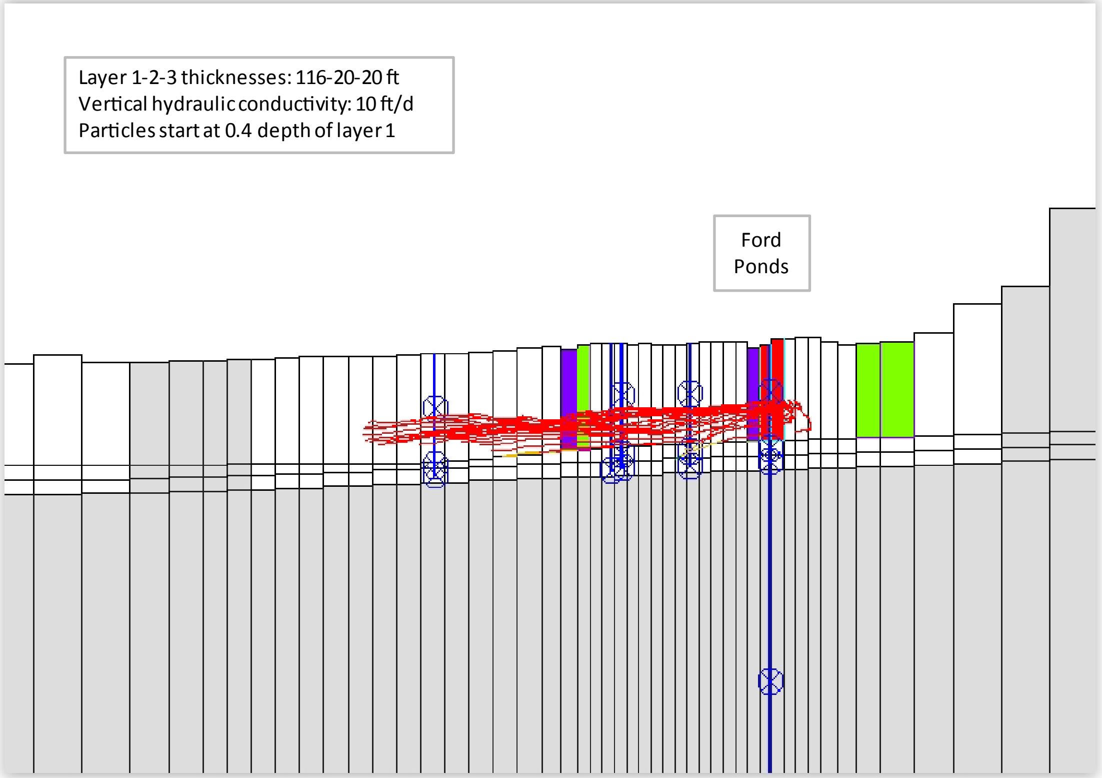


IPR - Indirect potable reuse

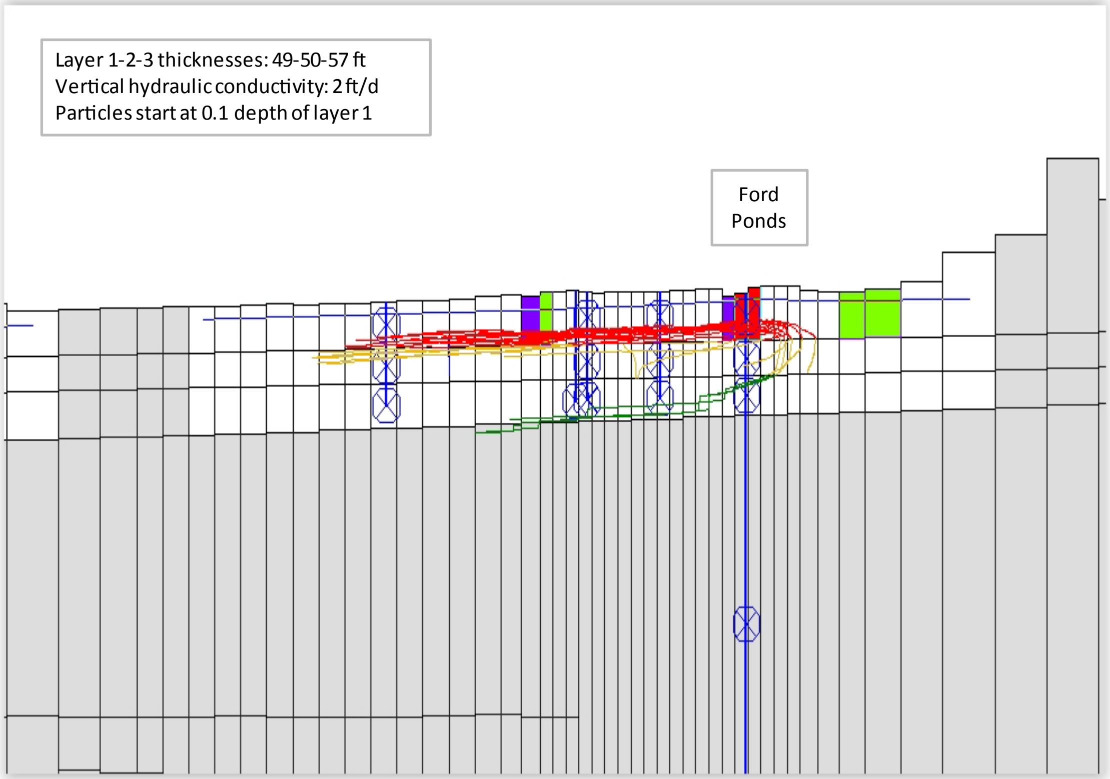
TODD GROUNDWATER

Figure 18
Sensitivity Test of Ford Ponds Area Particle Travel

19A. Original Simulation


Layer 1-2-3 thicknesses: 116-20-20 ft
Vertical hydraulic conductivity: 10 ft/d
Particles start at 0.4 depth of layer 1

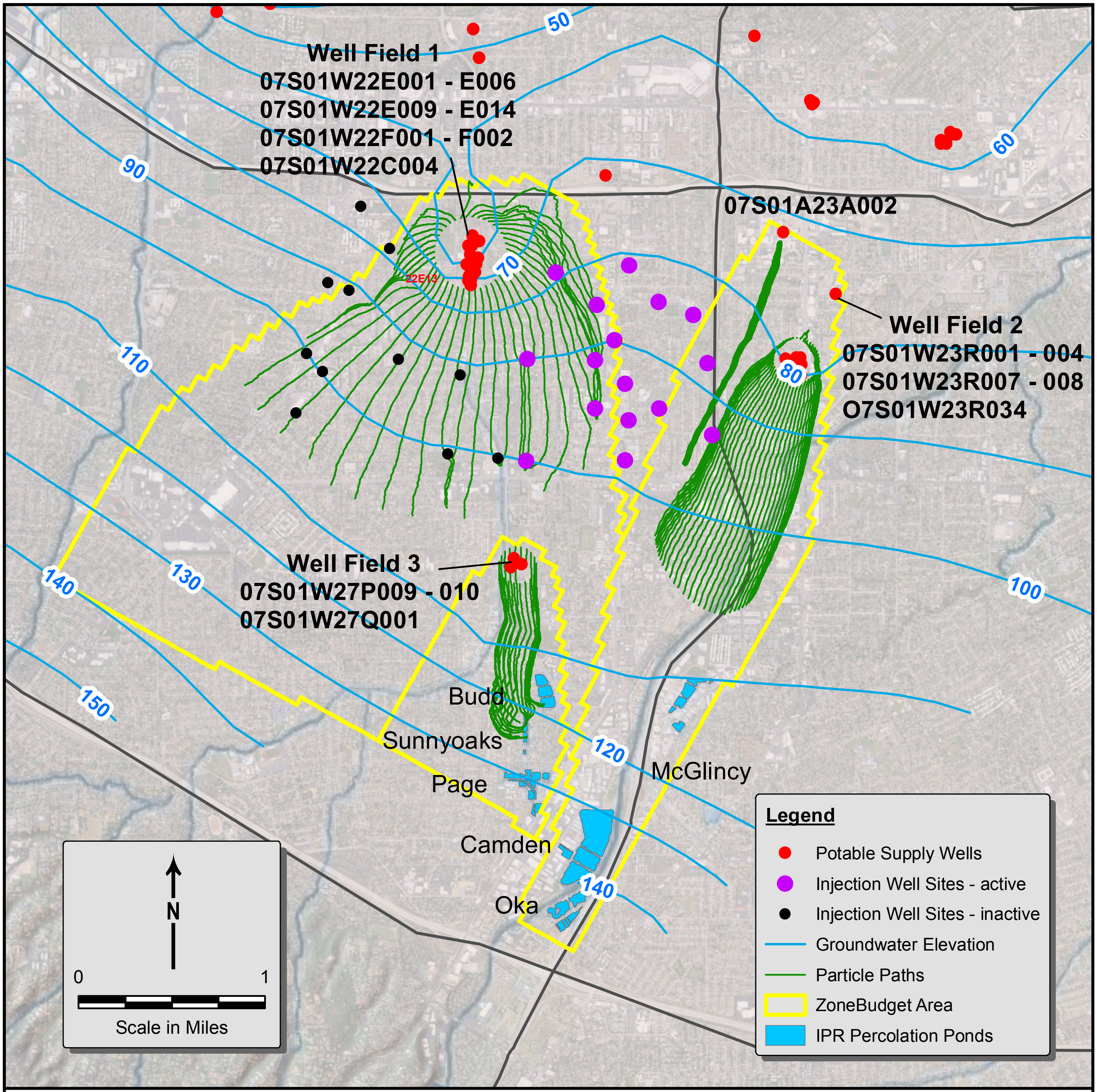
19B. Sensitivity Test Simulation


Layer 1-2-3 thicknesses: 49-50-57 ft
Vertical hydraulic conductivity: 2 ft/d
Particles start at 0.1 depth of layer 1

ft - feet
ft/d - feet per day

TODD GROUNDWATER

Figure 19
Sensitivity Test of Particle Tracking Parameters



Notes:

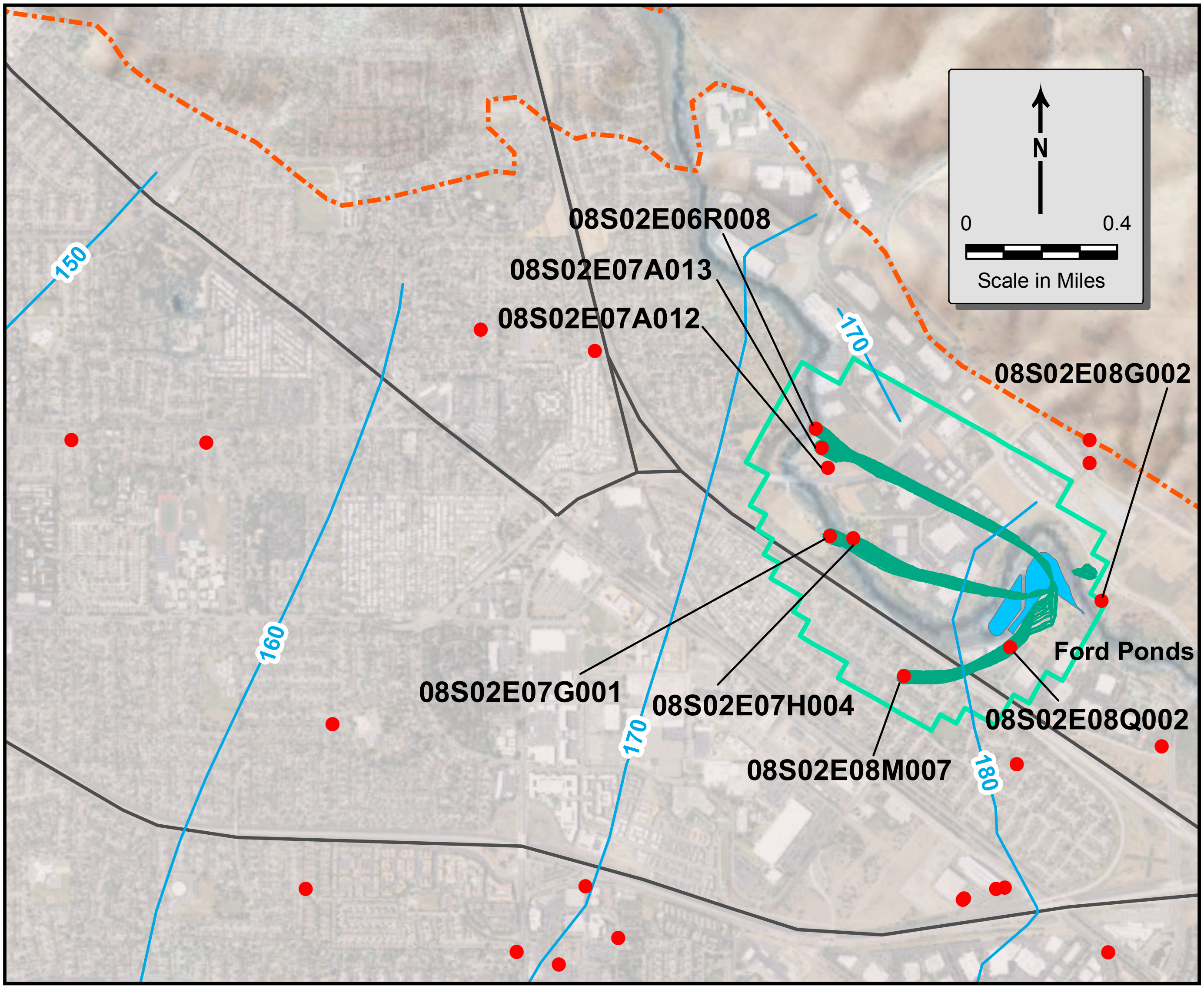
Simulated groundwater elevations are for layer 5, in feet above NGVD 1929.

Results shown are for Scenario 5.

IPR - indirect potable reuse

TODD GROUNDWATER

Figure 20
Reverse Particle Traces and ZoneBudget Area, Los Gatos Ponds and Injection Well Areas



Legend

- ● Potable Supply Wells
- Groundwater Elevation
- Particle Paths
- ▭ ZoneBudget Area
- ■ IPR Percolation Ponds
- ▭ Santa Clara Plain Subbasin

Notes:

Simulated groundwater elevations
are for layer 3, in feet above NGVD 1929.

Results shown are for Scenario 5.

IPR - indirect potable reuse

TODD
GROUNDWATER

Figure 21
Reverse Particle Traces and ZoneBudget Area, Ford Ponds Area